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# The Journal of the Iron and Steel Institute.

No. II.—1889.

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# PROCEEDINGS

OF THE

# IRON AND STEEL INSTITUTE.

## *PARIS MEETING*, 1889.

### TUESDAY, SEPTEMBER 24TH.

THE AUTUMN MEETING of the INSTITUTE was opened this forenoon at the hall of the *Société d'Encouragement pour l'Industrie Nationale*, Rue de Rennes, Paris.

RECEPTION OF THE INSTITUTE.

M. GUSTAV EIFFEL (President of the *Société des Ingénieurs Civils*) expressed the great delight that the French engineers had in receiving their English brethren. They desired to give them a hearty welcome, for they owed their friends a debt, knowing full well with what courtesy the French engineers were received in England. They regarded English engineers with sympathy as their educators and masters in metallurgy, and they desired to show by the heartiness of their reception the esteem with which they regarded them.

M. HATON DE LA GOUPILLIÈRE (President of the *Société d'Encouragement pour l'Industrie Nationale*) also joined in the welcome to the members of the Institute. As a mining engineer, he desired to say how much the Iron and Steel Institute excited their sympathy, and he congratulated the meeting on the relations which existed between the engineers of the two countries.

Sir JAMES KITSON, President of the Institute, then took the chair, and said he desired to express to M. Eiffel, a gentleman who had made an European reputation by his magnificent work of construction in that city, and also to M. Goupillière, the thanks of the meeting for the kind reception which had been given to them. They were aware of the extensive preparations which French hospitality had made ready for them. They were always glad to visit their *beau Paris,* to see its beautiful monuments and its intelligent people. They were always delighted to view the fertile plains of *La Belle France.* They had a vivid remembrance of the graceful hospitalities which were dispensed to them in 1878, and they knew that on the present occasion their great engineers and ironmasters had freely opened their works and the examination of their processes to the members of the English iron trade. On behalf of the Institute, he desired to thank them for their kindness, with a vivid sense of all the favours and the graceful courtesy which they were to receive during the present week.

The minutes of the previous general meeting were then read, confirmed, and signed by the President.

## THE SPECIAL BESSEMER GOLD MEDAL FOR 1889.

The PRESIDENT said he had to make an announcement with reference to the presentation of the Bessemer Gold Medal. At a recent meeting in London, the Council resolved to present M. Henri Schneider with a special Bessemer Medal for services rendered to the iron and steel trades of France. It was M. Schneider's intention to have been present to receive the medal, but in consequence of engagements at Le Creusot he was unable to attend. It was, therefore, proposed that the Medal should be presented to him on the occasion of the visit of the members to Le Creusot on Friday. It had, however, become necessary to modify their arrangements. He (the President) had arranged to go with another party to visit the Loire, and he would have the honour of being accompanied by M. Eiffel, who was kind enough to say that he would conduct that deputation. Sir Lowthian Bell had been good enough to accede to the request of the Council that he should head the party proceeding to Le Creusot, and he would formally present the Bessemer medal to M. Schneider

in the presence of the *employés* at Le Creusot, and the members who would visit that place. He hoped that that arrangement would meet with the approval of the members present.

The PRESIDENT then delivered the following :—

## PRESIDENT'S ADDRESS.

It is now my duty formally to open the business of this meeting, and having regard to the important and extended list of communications set down for consideration, I am obliged to be brief. But I must be permitted, by way of justification, if it be needed, for the remarkable promise of the reception which is prepared for us, to make a short statement as a presentation of credentials to the distinguished engineers and metallurgists who receive us with such marked courtesy and consideration.

We met last in Paris, in the year 1878, under the distinguished Presidency of the late Sir William Siemens. Our members then numbered 900. At the end of 1888 we had 1355 members—we have added this year 125—making our total of members 1480—an increase of 580, or nearly 65 per cent. since we last met here. Of these, some 200 are not resident in the United Kingdom, so you will agree that we have some claim to be ranked as a cosmopolitan institution. Further, it is practically since the Paris meeting that the Siemens-Martin open-hearth process and the Thomas-Gilchrist basic process have been commercially developed; and it is certainly in a considerable measure owing to the opportunities afforded to the inventors to make the value of their processes known and understood, and also to obtain the fruit of qualified criticism and practical suggestion, that the rapid publication and extended application of those new processes are largely due.

All the principal iron and steel works, and most of the chief collieries of Great Britain, have representatives amongst those who are members of this Institute, so that we very fully represent the industries on which the commercial prosperity of our country is founded, and upon which its security stands.

The production of coal in Great Britain last year (1888) amounted to 170 millions of tons, of which quantity we exported

27 millions, leaving for home consumption 143 millions of tons. Last year we raised more coal than ever before. According to the statement made by Professor Jordan, in the paper which will shortly be presented to you, France raised, in 1887, 21,288,000 tons of coal, and consumed 31,191,000 tons, so that we exported from England 6,000,000 tons more coal than the total quantity raised in France, and we raised in Great Britain last year eight times as much as the whole produce of coal in France.

Our production of pig iron in 1888 was 8,000,000 tons, our exports of iron and steel were 4,000,000 tons, and our home consumption was about 4,000,000 tons.

Our production of Bessemer steel ingots in 1888 was 2,012,794 tons, and our production of Siemens-Martin open-hearth ingots in 1888 was 1,292,742 tons, say 1,300,000 tons.

The simple statement that we exported last year 4,000,000 tons of iron and steel conveys but an imperfect idea of the value and advantage of cheap raw material for our manufactures, as you will see when I tell you that, in addition to our exports of hardware and cutlery, iron, and steel, amounting in value to more than £30,000,000 sterling, we exported machinery and mill work, and railway work, of the value of £16,000,000.

I may be excused for thus pointing out the advantages Great Britain possesses in the abundant supply of raw material at moderate prices, for in the hands of French engineers I can see no limit to their use of iron and steel for constructive purposes, if similarly supplied. The Eiffel Tower, that solid yet graceful construction, rears aloft its fairy-like form, an elegant example of the scientific powers and the imaginative genius of French engineering. It has been sometimes remarked that we English, although eminently practical, have not availed ourselves to the fullest extent of scientific control in our works. However that may be, it is not unreasonable to conceive that the possessor of abundant supplies of pure fuel, and of cheap mineral, might waste in minute savings the opportunities of rapid developments and realisations. But it is clear that the very necessities of the situation have in France attracted French chemists to the study of the processes of metallurgy. They have rendered great services, not only to their own native industry, but to the world at large. We are bound to offer this tribute to French scientific men.

It was the late M. le Chatelier who suggested to our eminent past-President, the late Sir William Siemens, that the regenerative furnace might be made available for the production of open-hearth steel, and in the year 1863 the first furnace specially designed for the purpose was erected at the Montluçon Works in France. MM. Pierre and Emile Martin had long been labouring to develop this process, which, by their alliance with Siemens, they made an absolute success.

The experiments made by M. de Wendel, an esteemed member of our Institute, to use phosphoric iron in the Bessemer process, and those of the chemists at Terre Noire, were fruitful experiences.

But the merit is justly attributed to M. Gruner, of Paris, of having first recommended the use of lime in order to render the slag basic instead of acid.

At our meeting in Paris in 1878, M. Gruner stated, in the discussion on M. Perisse's paper, that the use of basic linings was required to effect dephosphorisation. This was about that time effected by Messrs. Thomas and Gilchrist, who, aided by the inventions of Mr. G. J. Snelus and Mr. Edward Riley, have rendered immense services to the owners and workers of phosphoric ores throughout the world.

The paper prepared by Messrs. Thomas and Gilchrist was on the list of papers presented at the Paris meeting of 1878, but it was not read, because the Council felt bound, in courtesy, to take first the papers by French authors, and consequently it was deferred.

It was read and discussed at the meeting of the Institute in London, in May 1879.

Within ten years the manufacture of basic steel has been created, and now, within this short period, the production last year was 2,000,000 tons (1,953,234), of which France produces 174,721 tons.

Within ten years from the commencement of the process, 8,571,851 tons of basic steel have been produced, the make being thus divided:—

| | Tons. |
|---|---|
| England . . . . . . . . . . . . | 1,715,847 |
| Germany, Luxembourg, and Austria . . . . | 5,608,386 |
| France . . . . . . . . . . . . | 864,713 |
| Belgium and other countries . . . . . . | 382,905 |
| Total . . . . | 8,571,851 |

The basic steel made in France last year was probably one-fourth to one-fifth of the total make.

At the end of this month the make of basic steel will have reached 10,000,000 tons.

There were also made last year 600,000 tons of slag, containing about 36 per cent. of phosphate of lime, most of which was simply ground very fine, and used as a fertiliser without any other treatment.

We do not forget the valuable contributions made to the discussions at our meeting in Paris by M. Tresca; and in view of the advent of the general use of the forging press, M. Tresca's researches into the laws which rule the flow of solids are worthy of special technical study by those who direct the use of this new mode of working steel.

When I addressed you in May, I alluded to the subject of alloys of iron and steel, which, I remarked, are destined to play a more and more important part in industry. I call your attention to this subject again for the purpose of recording that this line of research has received much attention from French metallurgists, at the International Congress on Mining and Metallurgy, and a very interesting and exhaustive report has been presented by M. Gautier, a member of our Institute, on alloys of iron and steel.

The alloys of iron and chromium have been investigated and reported upon by M. Brustlein. Valuable and systematic research has been made into the processes of tempering and annealing by M. Osmond, and the use of metallic baths for the tempering of large masses has been dealt with by M. Evrard.

I hope the Council may be able to give a *résumé* of these papers in the *Journal* of the Institute.

The enormous development of the use of steel castings in the period which has elapsed since our last visit to France is one of the features of the day, and it is undoubted that at the Terre Noire Works, when the researches of M. Gautier, M. Euverte, and others gave that establishment a distinct pre-eminence as makers of steel castings, a lead was given which has been followed in Great Britain and elsewhere.

I have said but little in the few observations I am permitted by the limited time at my disposal, but enough, I think, to prove

that the Iron and Steel Institute has, by its papers, its discussions, and its interchange of ideas, materially quickened the pace at which new inventions and new methods are introduced.

It has rendered great services to the material progress of the world, and has some claim to accept the kind welcome and the graceful reception which the heads of the French iron and steel trade are at this time so generously giving to us.

## New Members.

The President proposed that Mr. David Evans of Barrow and Mr. S. Lloyd of Wednesbury be appointed scrutineers of the voting-papers. These gentlemen announced, on the completion of their scrutiny, that the whole of the candidates proposed for membership had been duly elected, namely :—

Atkinson, Edward T. .......... Stalybridge.
Barningham, Robert B. .......... Manchester.
Bedford, Joseph .......... Sheffield.
Bell, Robert .......... Edinburgh.
Bellhouse, Ernest .......... Dunham Massey.
Byers, William Lumsden .......... Sunderland.
Davenport, Russell W. .......... Bethlehem, Pa., U.S.A.
Davies, Jasper Gustavus Silvester .......... Middlesbrough.
Davies, William .......... Sheffield.
Davy, Charles .......... Sheffield.
Devereux, Walter B. .......... Colorado, U.S.A.
Dickson, John .......... Grosmont, Yorkshire.
Dreux, A. .......... Mont St.-Martin, France.
Duncan, David John Russell .......... London.
Edwards, Daniel .......... Morriston.
Edwards, Wm. Henry .......... Morriston.
Evans, Evan D. .......... Barrow-in-Furness.
Fellowes, Samuel James .......... Wolverhampton.
Firbank, Joseph Tom .......... London.
Firth, William Edgar .......... Philadelphia, U.S.A.
Freeston, Thomas Edgar .......... Wellington.
Graham, Alexander Macdougal .......... Glasgow.
Gregory, Joseph .......... Manchester.
Gubbins, R. R. .......... Erith, Kent.
Harris, Anthony .......... Middlesbrough.
Henderson, Norman M'Farlane .......... Broxburn.
Hingley, George *Benjamin* .......... Dudley.

| | |
|---|---|
| Horsfield, Samuel | Newton, N.B. |
| Hunt, Charles | Birmingham. |
| James, Charles Henry | Merthyr Tydvil. |
| Jaques, William Henry | Bethlehem, Pa., U.S.A. |
| Jopling, Thomas | Cleveland, U.S.A. |
| Jordan, Albert Edward | Birmingham. |
| Jowitt, Charles Albert Renny | Sheffield. |
| Kitson, Albert Ernest | Leeds. |
| Korten, Rudolph | South Bank, Yorkshire. |
| Lee, Henry | Prestwich. |
| Lopes, George | London. |
| Marshall, Francis Carr | Newcastle-on-Tyne. |
| M'Murty, George Gibson | Pittsburg, U.S.A. |
| Muller, Thomas Neil | Middlesbrough. |
| Naylor, John William | Leeds. |
| Otis, Charles Augustus | Cleveland, Ohio, U.S.A. |
| Owen, David | Morriston. |
| Parkes, John Israel | Smethwick. |
| Pearce, Sir William George, Bart. | Wemyss Bay, N.B. |
| Pochin, Henry D. | Eglwysbach. |
| Preston, Fredk. Walter | Kettering. |
| Reimers, E. | Magdeburg, Germany. |
| Ridgely, William Barrett | Springfield, Illinois, U.S.A. |
| Roe, Pearce | London. |
| Rummens, Francis William | Shirley. |
| Sampson, Richard H. | Pontardulais. |
| Sauvée, Albert | London. |
| Siddell, George | Pitsmoor. |
| Slater, James | Walsall. |
| Smith, Henry John | Newmains, N.B. |
| Smith, Samuel | Wednesbury. |
| Thomas, John Glyn | Llangennech. |
| Thompson, Philip | Middlesbrough. |
| Triponé, Emile | Paris. |
| Twynam, Thomas | London. |
| Tylden-Wright, Charles | Dudley. |
| Walker, William Rose | Chicago, U.S.A. |
| Western, Charles Robert | London. |
| White, Maunsel | Bethlehem, Pa., U.S.A. |
| White, William Henry | London. |
| Widdop, Isaac | Mexbrough. |
| Williams, Peter | Wrexham. |
| Wilson, Lieut.-Col. G. H. | Bala. |
| Wood, Edward | Manchester. |

## Retiring Members of Council.

The General Secretary announced that the following Vice-Presidents and members of Council retired at the present meeting in accordance with Rule X.), namely:—

*Vice-Presidents.*

Mr. Wm. Evans. Mr. E. P. Martin.
Mr. Wm. Jenkins.

*Members of Council.*

Mr. G. J. Barker. Mr. Alfred Hewlett.
Mr. W. T. Crawshay. Mr. J. Riley.
Mr. G. J. Snelus.

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The following paper was then read:—

# NOTES ON THE IRON AND STEEL MANUFACTURE IN FRANCE IN 1887,*

## AND AS ILLUSTRATED BY THE FRENCH EXHIBITS AT PARIS.

By PROFESSOR S. JORDAN, Paris.

The author presented to the Paris meeting of the Institute in 1878 a paper entitled "Notes on the Resources of the Iron Manufacture in France," and tried thereby to give his English colleagues a summary idea of the French siderurgy at that time. That paper dealt especially with the fuels, iron ores, and blast furnaces of France. In this new paper, prepared for the second Paris meeting, the author intends to complete his former notes, and to bring forward the changes which have occurred during the last ten years. He will be obliged sometimes, for the sake of brevity, to refer to the 1878 paper.

### Section I.—Coal and Coke.

In his former paper the author has indicated the production of the French collieries, and especially the output of the six principal coalfields. He will now give, with some more details, the output for 1887, and compare it with the output for 1877, according to the official statistics.

* 1887 is the last year returned in the official statistics.

*Production of Coal and Coke in France in* 1887, *compared with* 1877.

| Coalfields. | 1877. | 1887. |
|---|---|---|
| | Tonnes. | Tonnes. |
| Northern coalfield | 6,720,000 | 11,317,000 |
| Loire coalfield | 3,340,000 | 2,989,000 |
| Gard coalfield | 1,660,000 | 1,831,000 |
| Burgundy and Nivernais coalfield | 1,380,000 | 1,497,000 |
| Central coalfield | 1,020,000 | 994,000 |
| Aveyron and Tarn coalfield | 975,000 | 1,076,000 |
| Auvergne coalfield | 240,000 | 291,000 |
| Herault coalfield | 238,000 | 208,000 |
| South Vosges coalfield | 186,000 | 186,000 |
| Creuse and Corrèze coalfield | 178,000 | 153,000 |
| Western coalfield | 237,000 | 136,000 |
| Western Alps coalfield | 132,000 | 132,000 |
| Total for coal and anthracite | 16,305,000 | 20,810,000 |
| Provençe and Alps brown coalfields | 470,000 | 457,000 |
| Sundry brown coalfields | 30,000 | 21,000 |
| Total for brown coal | 500,000 | 478,000 |
| Sum total | 16,805,000 | 21,288,000 |

*N.B.*—The French *tonne* is 1000 kilogrammes.

It will be seen that the coal output of France has increased in ten years by about 25 per cent., and that this increase has nearly altogether taken place in the Northern coal-field.

The coal consumption of France having been 31,191,000 tons for 1887 (instead of 24,144,490 tons for 1877), the foreign imports must have been 10,565,000 tons (including 4,046,000 tons of British coals), instead of 7,882,000 tons (including 2,867,000 tons of British coals), for 1877.

The author has shown in his 1878 paper how the French coal-fields are distributed over the country, and also that these coal-fields, excepting the six principal ones, are of somewhat small relative importance. The present International Exhibition affords to the visitors, more than any former one, the means for forming an accurate idea of the geological features, of the modes of mining, and of the quality of the products belonging to all the important French collieries.

The great *Northern coalfield* is represented in the "Palais des Machines" by the Anzin, Aniche, Escarpelle, Douchy, and Vi-

coigne collieries, situated in the department of the North, and by the Lens and Douvrin, Courrières, Bethune, Noeux, Bruay, Dourges, Fléchinelles, Lievin, Meurchin, and Drocourt collieries, situated in the Pas-de-Calais.

The *Loire coalfield* is represented by the four more important mining companies, viz., the Montrambert and Beraudière Company, the Loire Company, the St. Etienne Company, and the Roche-la-Moliére and Firminy Company. The coalfield, as a whole, is illustrated by an interesting plan in relief.

The several collieries of the *Gard coalfield* exhibit a very fine geological plan in relief of the coalfield as a whole, and each of them, viz., the Grand Combe, Bessèges, Portes and Senechas, Rochebelle, Trelys, Cessous and Comberedonde, Salles and Montalet has also its individual exhibits.

The *Burgundy and Nivernais coalfield* is represented by the beautiful exhibit of the Blanzy collieries, and by the geological maps of the Decize colliery (owned by Messrs. Schneider and Company).

The *Central coalfield* has sent plans in relief of the Saint Eloi and of the Bezenet collieries, as well as models of the Commentry colliery, prepared so as to illustrate the delta theory of coalfields formation put forward by M. Fayol.

The *Aveyron collieries* are represented in the metallurgical gallery by the plans and drawings of the Aubin mines; and the *Tarn collieries* in the "Palais des Machines" by the exhibits of the Carmaux Mining Company, and of the Tarn Mining Society.

The *Ronchamp colliery*, in the South Vosges, exhibits its plans and products.

The *Graissessac mines* (Herault) are represented in the "Metallurgical Gallery," as well as the *Bouches du Rhone lignite collieries*, which exhibit the brown coals of Greasque and the Rocher bleu.

Coke.—As to this fuel, the author can only repeat what he said in 1878. Coke is just now produced in France almost only in the improved coke ovens, called *Belgian coke ovens*, of the Smet, Coppée, or other analogous systems, in which the introduction of the coal to be carbonised is effected through hoppers placed in the arched ceiling of long rectangular and horizontal chambers or vaults, open at both ends, and the extraction of the coke is effected by means of mechanical steam pushing rams. The vertical

*Appolt ovens* are not now much in use; they are only to be seen at Blanzy, Creusot, and Bezenet. The obsolete beehive ovens are used only at one or two collieries, and can be seen in the exhibition of the Loire collieries; but their products are not intended for blast furnaces, and are only used for foundry purposes. The visitor can find in the exhibits at the Douchy, Escarpelle, and Dourges collieries some examples of improved plants for the manufacture of coke, and in some other collieries will be found specimens of the coke produced.

Coke is manufactured sometimes with only screened small coals, at other times with washed small coals, according to the purity of the fuel to be obtained. The so-called "*washed coke*" used for blast furneses contains generally from 6 to 10 per cent. of ash; the unwashed ones contain 10 to 12 per cent., and often more. The small coals carbonised are seldom of only one origin; the coke-makers rather try to obtain economical mixtures by associating the dearer coking coals with the largest possible proportion of the cheaper non-coking coals, so as to come as near as possible to the limit of the property of coking. These mixtures are made with great care by means of various apparatus, such, for instance, as the Carr disintegrator. The coke-makers have, in that way, been able to notably lessen the cost of production of coke, owing especially to the use of the Coppée and other improved ovens, which produce good coke with coals that would not cake in the beehive ovens. Messrs. Seybel & Bernard exhibit in the "Palais des Machines" some drawings of improved coke ovens specially intended for the coking of meagre coals.

Messrs. Schneider & Co. have tried at Le Creusot a new form of vertical coke oven, known as the *Bauer system*; but the author would require some further data as to the results obtained in order to be able to speak of these ovens.

The application of coke ovens to the production of tar and ammoniacal salts has found a place in some collieries, as at those of Bessèges, Alais, Terrenoire, St. Etienne (*Carvès ovens*), and the Campagnac colliery (*Seybel ovens*); but commercial circumstances have not favoured the extension of the manufacture of bye-products. The author believes that for some years past no other ovens have been built in France for that purpose; besides, the quality of the coals used here for the production of coke does not

suit this special industry of bye-products so well as the English or German coals.

## Section II.—The Pig Iron Manufacture.

According to the official statistics, the comparison of the pig iron production in France for the years 1877 and 1887 is as follows:—

| | 1877. | 1887. |
|---|---|---|
| *Pig Iron Production*— | Tonnes. | Tonnes. |
| Coke pigs . . . . . . . | 1,372,000 | 1,547,000 |
| Charcoal pigs . . . . . . | 80,000 | 12,000 |
| Coke and charcoal pigs . . . . | 54,000 | 9,000 |
| Sum total . . | 1,506,000 | 1,568,000 |
| *Number of Furnaces in Blast*— | | |
| Coke blast furnaces . . . . . | 133 | 84 |
| Charcoal blast furnaces . . . . | 69 | 12 |
| Coke and charcoal mixed blast furnaces | 30 | 5 |
| Sum total . . . | 232 | 101 |
| *Consumption of Raw Material*— | | |
| Coke . . . . . . . . | 1,900,000 | 1,800,000 |
| Wood charcoal . . . . . . | 150,000 | 15,000 |
| Iron ores . . . . . . . | 3,323,000 | 3,453,000 |
| Indigenous ores . . . . . | 2,346,000 | 2,298,000 |
| Algerian ores . . . . . | 330,000 | 48,000 |
| Foreign ores . . . . . . | 647,000 | 1,107,000 |

These figures indicate that important changes have taken place during the ten years that have elapsed since the 1878 Exhibition.

The production of *charcoal pig iron* has continuously decreased, and now shows only an unimportant tonnage. There were in 1887 only a few charcoal furnaces, viz., some of them in the south-west of France, making special grey pig for gun-making purposes; two only in the Franche-Comté district, producing the grey charcoal pig so highly reputed in bygone times for the charcoal refinery; one in the Alps (Isere), and one in the Western Pyrenees. These two latter are represented in the metallurgical gallery of the Champ de Mars, and are worth notice, if only for their now unique character.

The Brignoud blast furnace (Isere) is smelting alpine spathic ores, and produces the excellent charcoal pigs used in the

ırtuis Steelworks for the production of steel by charcoal ι refining.

ı Ria blast furnace (Western Pyrenees), belonging to Messrs. ıltzer & Co., is producing, with the manganiferous brown ites, and the spathic ores of the country, grey and white ıniferous pigs, used in the Unieux Steelworks for making celebrated products.

ɜ smelting of iron ores *with a mixture of coke and charcoal* local and temporary peculiarity, and this practice is dis- ring more and more, either because the blast furnace s, who, being unable to use coke only owing to the small- f their plant, mixed coke with charcoal in order to lessen ›st of production, have finally put their furnaces out of or because they have decided to build larger furnaces, and ɜ coke alone. In 1887, there were only very few blast es using mixed fuels, and they were located in the east of ɘ, in the part which the author called, in his 1878 paper, ıampagne district, and where the furnaces using only char- ave disappeared. It looks probable that the use of mixed ›xists no longer, and certainly nothing can be seen of it in chibition.

› *production of pig iron by means of coke* is therefore now ıly important branch of the French pig iron trade. The · reported to the Institute in 1878 as to the geographical ıution of the blast furnaces in France. The following ıent will show the changes since that time:—

*Furnaces in blast.*

| Districts. | 1877. | 1887. |
|---|---|---|
| North and Pas-de-Calais district | 16 | 12 |
| Meurthe and Moselle district | 32 | 31 |
| Champagne district | 59 | 14 |
| Franche-Comté district | 9 | 2 |
| Central district | 21 | 7 |
| North-Western district | 13 | 1 |
| Perigord and Aveyron district | 19 | 4 |
| Pyrenees and Landes district | 18 | 11 |
| Loire and Rhone district | 29 | 10 |
| Alpine district | 6 | 3 |
| South-Eastern district | 10 | 6 |
| | 232 | 101 |

The total number of blast furnaces has decreased more than one half, but the pig iron production has nevertheless increased. From about 6500 tons the mean annual make per furnace has increased to 15,500 tons, and, if the details were looked for, it would be found that the progress in this respect has occurred in the two first districts, and, above all, in the Meurthe and Moselle district, which, with less than a third part of the total number of the French furnaces, has produced more than one-half of the total annual make of pig iron.

Proceeding now to rapidly review the various pig-making districts, the author will indicate the changes that have occurred since 1878, and at the same time point to the corresponding exhibits. As to the iron ore resources, he is obliged to refer the reader to his 1878 paper.

*North and Pas-de-Calais district.*—In this district the blast furnaces are smelting almost entirely Bilbao hematites and Meurthe and Moselle oolitic ores.

The more recently built ironworks, those of Isbergues (Pas-de-Calais), whose exhibits are to be seen in the Metallurgical Gallery, produce only Bessemer iron with Bilbao ores. The mean daily make of the two blast furnaces at these works exceeds 225 tons.

The Denain blast furnaces, whose model is exhibited in the "Palais des Machines," are smelting the same ores, and producing the same quality of iron.

The Anzin and the Maubeuge Ironworks (Northern Ironworks annexe) produce forge and foundry pigs by smelting chiefly oolitic Moselle ores.

The older blast furnaces in the neighbourhood of Boulogne, which formerly smelted local ores mixed with imported ores, are now out of blast.

*Meurthe and Moselle district.*—This district, by far the most important as regards the make of pig iron, employs only oolitic ores, obtained from the large Eastern ironstone field, which extends from the vicinity of Nancy to Luxembourg, through German Lorraine.

The fuel used here is either French coke from the Northern coalfield, or Belgian or Westphalian coke.

The blast furnaces produce either foundry or forge pigs, and

also the so-called Thomas pigs for the basic process. Those making this latter quality import foreign manganiferous ores (those of Germany, Spain or Greece). The oolitic ores, which yield pigs with 1½ per cent. and more of phosphorus, do not contain enough manganese for the Thomas pigs. According to official statistics, the Meurthe and Moselle district produced in 1887 about 220,000 tons of Thomas pig; but this production can easily be increased.

The four blast furnaces at Jœuf near Briey (Messrs. de Wendel) make exclusively Thomas pig; they are not represented in the Exhibition.

The Longwy Steelworks Company, which owns at Mont-Saint-Martin six furnaces, exhibit in the Metallurgical Gallery the whole range of its raw materials and products, specially Thomas pig, the analysis of which are given as follows:—

| | White Thomas Iron. | Mottled Thomas Iron. |
|---|---|---|
| | Per Cent. | Per Cent. |
| Manganese | 1·50 | 2·00 |
| Carbon | 3·00 | 3·20 |
| Silicon | 0·20 | 0·35 |
| Sulphur | 0·04 | 0·02 |
| Phosphorus | 2·00 | 2·20 |

The North and East Steelworks Company make in their four blast furnaces at Jarville, near Nancy, Thomas pig iron for its Valenciennes Steelworks, using its own oolitic ores, mixed with imported manganiferous ores. Its exhibits are to be seen in the Northern Ironworks annexe.

Many other blast furnaces in the district could also produce Thomas pig; but so far as the author knows, none of them produce it regularly. They are mainly engaged in making foundry and forge pig for local consumption, or for consumption in other districts of France. Some of them are represented in the Exhibition, either in the Metallurgical Gallery, or in the special annexe of the Northern Ironworks. They are as follows:—

The fine Pompey Ironworks, belonging to Mr. Fould Dupont, with two furnaces, yielding daily each 110 to 115 tons of forge pigs;

The Maxeville furnaces belonging to the Vezin-Aulnoye Company;

The Pont à Mousson furnaces, which exhibit very beautiful drawings of their plant, including an important pipe foundry;

The Frouard furnaces, owned by the Montataire Company;

The Gorcy furnaces on the Belgian border;

The Villerupt furnaces, belonging to the Chatillon-Commentry Company;

The Micheville Ironworks, belonging to Messrs. Ferry, Curicque, and Co., which include two blast furnaces, yielding each daily eighty to ninety tons of foundry pig, or 120 tons of forge pig.

Below is the composition of the Micheville pig iron, which will give an idea of the general quality of the iron made in this district:—

| | Foundry No. 3. Per cent. | White Forge. Per cent. |
|---|---|---|
| Graphite | 2·50 | ... |
| Combined carbon | 0·70 | 2·75 |
| Silicon | 2·40 to 2·75 | 0·30 to 0·60 |
| Sulphur | 0·02 to 0·05 | 0·25 to 0·50 |
| Phosphorus | 1·60 to 2·00 | 1·60 to 2·00 |

Some of these works are smelting Luxemburg ores of the same character as the oolitic ores of the Meurthe and Moselle.

*Champagne district.*— This district has lost much of its former importance as a pig iron producer. Its blast furnaces are smelting local ores, associated with more or less Meurthe and Moselle ores.

The Champagne Forges Company exhibit specimens of their Pont-Varin-Wassy ironstones, which are mixed for special purposes with Pont-Saint-Vincent oolitic ores and manganiferous ores, as well as specimens of the pigs produced and used for the basic Siemens-Martin process.

The other works are only represented by various iron castings, some of them for ornamental, and others for building purposes.

*Franche-Comté district.*—The two operative blast furnaces of this district have not exhibited anything.

*Central district.*—There are no longer any charcoal furnaces in this district, which is represented only by the coke furnaces of Montluçon-Ville (of the Commentry-Fourchambault Company), and by those of the two Montluçon-Saint-Jacques and Commentry Works (of the Chatillon-Commentry Company). These furnaces smelt the local pisolitic ores mixed with imported

Algerian or Spanish ores. The pig iron they produce is used for foundry purposes, or for making iron and steel. Some of them have also occasionally produced ferro-manganese and ferro-chromium.

*North-Western district.*—The older blast furnaces of this region have disappeared, and the author can only point to the newly-built Saint-Nazaire furnaces, which are smelting Bilbao ore with English coke, and which have not exhibited.

*Perigord and Aveyron district.*—This region has also lost much of its importance; it is only represented in the Exhibition by the Fumel furnaces, though some more coke furnaces are in blast at Decazeville and Saut du Tarn, and one or two charcoal furnaces are found in the Dordogne department.

*Pyrenees and Landes district.*—The largest ironworks in this district are now the Boucau or Adour Ironworks, belonging to the "Forges et Acieries de la Marine et des Chemins de fer" Company. These works, recently built as those of Saint-Nazaire, exhibit in the Metallurgical Gallery the hematite pig iron it produces, chiefly with Bilbao ores, for Bessemer and open-hearth steel-making, as also ferro-chromium containing up to 65 per cent. chromium.

The Ariège Forges Company also own blast furnaces at Tarascon and Berdoulet.

Messrs. Jacob Holtzer & Co. own the Ria charcoal furnace already spoken of.

*Loire and Rhone district.*—This region is largely and admirably represented in the Exhibition, although its pig iron production has much diminished since 1878. Its iron and steelworks are now using large quantities of pig iron obtained from other districts of France, and its remaining blast furnaces chiefly produce special qualities of pig iron for the making of superior iron and steel, by using Algerian and Spanish, Alpine, and Pyrenean ores, and also some local ores.

The exhibits of the Pouzin blast furnaces (Horme Company's special annexe) will give an idea of the variety of the qualities of pig made in this region. There can be seen, with the corresponding analyses, *ordinary pigs* for foundry and forge (eight classes) made with the Veyras red ores only, *special pigs* (five classes), *superior pigs* (five classes) made with the Veyras ores

mixed with some foreign ores, *pure pigs* made with the excellent Pyrenean and Algerian ores. The percentage of sulphur decreases from 0·48 per cent. in the white ordinary forge pigs to 0·02 per cent. in the grey pure pigs; the percentage of phosphorus from 0·27 per cent. in the ordinary, to 0·05 per cent. in the pure pigs.

The Firminy Company possess one coke blast furnace (about 7000 cubic feet capacity), which can yield daily 120 tons of ordinary pig, but which is more usually making superior pig, spiegeleisen, and silico-spiegels (with a silicon percentage exceeding 20 per cent., according to the exhibited figures). In this last mode of working, the daily yield decreases to 10 or 15 tons. The ores used come from Algiers and Spain.

The "Forges et Acieries de Saint Etienne" Company also own blast furnaces at Chasse (Isere), but exhibit no pig iron.

The Givors blast furnaces belonging to Messrs. de La Rochette et Cie. produce almost exclusively foundry pigs for castings.

The more important works of this district, Le Creusot, are not represented in the Exhibition, nor are the Terrenoire and Lavoulte ironworks.

Some of the ironworks in the Loire region are using, for the production of superior iron and steel with ordinary pig, a special refining process (*Rollet's process*). It consists in the melting of the pig with an extra-basic slag, obtained by means of fluorspar and limestone. This melting is effected in a basic-lined or water-jacketed cupola furnace, blown by hot blast. The pig iron is thus purified by the removal of the greater part of its sulphur, and of a certain portion of its phosphorus. The fined metal obtained is sometimes cheaper than the pure pig made with manganiferous foreign ores. The Rollet process is not formally exhibited, but its products can be seen among the exhibits of the Holtzer and Firminy Companies.

*Alpine district.*—This small district is represented by the only two blast furnaces that it now contains, the Brignoud charcoal furnace, already spoken of, and the Allevard coke furnace (A. Pinat & Co.), yielding daily 19 to 20 tons of superior pig (grey, white, mottled, and specular), by smelting the celebrated local spathose ores.

*South-Eastern district.*—Here the blast furnaces employ chiefly imported ores from Algeria, Spain, &c.

The Saint Louis Marseilles Ironworks exhibit an interesting set of products:—Superior foundry and forge pigs, spiegeleisen, ferro-manganese (up to 87 per cent. manganese), silico-spiegel (up to 14 per cent. silicon), ferro-silicon (up to 14 per cent. silicon), and ferro-chromium (up to 65 per cent. chromium).

The Tamaris furnaces (Alais Ironworks Company) exhibit their raw materials and products. Amongst the former can be seen coke made in the Carvès ovens, iron ores from the Gard, the Pyrenees, Algeria, Spain, &c., manganese, and chromium ores. These works, indeed, produce a wide range of qualities of pig: foundry pigs (six classes), forge pigs (four classes), spiegeleisen and ferro-manganese of various percentages, with ferro-chromium and ferro-silicon.

The Beaucaire furnaces (Chatillon-Commentry Company) exhibit only ferro-chromium.

It may be observed that the furnaces in this region chiefly produce various sorts of iron, and alloys of iron, intended for special purposes, and export them to other steel-making districts. These furnaces have supplied with their special products, such as spiegeleisen, ferro-manganese, &c., many iron and steel works in various European countries, and even in America.

## Section III.—Manufacture of Wrought Iron and Steel in Open Fires and in Puddling Furnaces.

The introduction of the new and economical processes for manufacture of cast steel has effected great changes in the iron industry of France as well as of other countries. The following statement, taken from the official statistics, gives an idea of these changes since 1878:—

| | 1877. | 1887. |
|---|---|---|
| Number of puddling furnaces (iron) . . . | 995 | 637 |
| „ „ (steel) . . . | 51 | 35 |
| Number of open-fires (iron) . . . . . | 243 | 53 |
| „ „ (steel) . . . . | 6 | 5 |
| Production of puddled iron . . . . . | 821,006 tons. | 617,997 tons. |
| „ of charcoal refined iron . . . | 63,487 „ | 16,864 „ |
| „ of puddled and charcoal-refined steel | 20,273 „ | 12,532 „ |

These figures are sufficiently expressive, and the author does not think it necessary to discuss them specially.

As to the *manufacture of wrought iron by converting pig iron in open-fires and using charcoal as fuel*, or as to the so-called *charcoal wrought iron*, nothing is to be learned in the Exhibition, this description of iron not being represented. However, a few charcoal open-fires are still working, especially in the Franche-Comté and the Berry provinces.

The so-called *natural steel*, obtained by the same mode of treatment of pig iron, or *charcoal natural steel*, can be seen among the exhibits of Mr. Alphonse Gourju (Bonpertuis Steelworks), and perhaps of Messrs. Gouvy & Company (Dieulouard Steelworks) in the Metallurgical Gallery, together with shear and double shear steel, made by piling and welding this natural steel. These descriptions of steel are almost solely used for manufacturing agricultural implements and edge tools by some antiquated ironworks, and the output is now very small.

*Puddled steel* is still manufactured in some steelworks of the Alpine district (the Allevard Works, for instance), and more particularly in the Loire district. Messrs. J. Holtzer & Co. exhibit so-called *natural steels* intended for cutlery, edge tools, agricultural implements, springs, &c., and obtained by puddling the charcoal pigs of their Ria furnace. The Saint Chamond Steelworks, and the Firminy Steelworks also exhibit puddled steel, as well as the Dieulouard Steelworks (Meurthe and Moselle), and the Saint Jacques de Montluçon Steelworks (Central district), belonging to the Chatillon-Commentry Company. We have, however, already seen that the annual output of puddled steel is now very small: this process is gradually disappearing, and, besides, it is rather difficult to draw a clear line of demarcation between puddled steels and superior fine-grained puddled irons.

As to *puddled iron*, the annual output is also gradually decreasing, owing to the gradual increase of the use, for structural and mechanical purposes, of soft cast steels, obtained in the converter or in the open-hearth. The author does not find much interesting matter to offer about this description of iron.

For a long time the French ironworks have been in the habit of methodically arranging in somewhat numerous numbers or classes (4, 5, 6, and even more) the different qualities of muck bars, so as to have merchant bars, plates, and sheets of the same classes. The lowest number was used for the iron rails, and

therefore its make has now greatly decreased. Iron-manufacturers are more and more eagerly trying to obtain varieties of wrought iron well defined, either by their mechanical properties (breaking stress, elastic limit, and elongation), or by their applicability for special uses. An examination of the various examples of merchant iron exhibited in the Champ de Mars will illustrate this practice for the visitor.

*The preliminary fining of pig iron*, before puddling, is now used only in very few ironworks. The Exhibition, however, permits us to point to the Gier forges (belonging to the Horme Company), to the Unieux and to the Firminy Steelworks, where the Rollet process of fining is in practice.

In reference to the plant of puddling forges, the author can point to the more extended use of double-puddling furnaces, which are adapted to receive heats as heavy as 500 kilogrammes, especially in the ironworks of the North, and of the Meurthe and Moselle districts.

*Mechanical puddling* is not much used in France. There are, nevertheless, some furnaces provided with mechanical or automatic stirrers, or rabbles, according to the *Lemut* or analogous systems, especially in forges using Meurthe and Moselle pigs; as well as some furnaces with round revolving hearths, such as the *Pernot system* in the Saint Chamond Steelworks, and also some rotating furnaces of the *Bouvard system*, invented by this metallurgist, in the Creusot Steelworks for the making of superior puddled iron to be melted in the open-hearth.

## SECTION IV.—MANUFACTURE OF STEEL IN CONVERTERS.

According to the official statistics, there were twenty-four Bessemer converters at work in France during the year 1877, but no data are given as to their output. The data for 1887 are as follows:—

| | |
|---|---|
| Converters in activity | 28 |
| Total output | 324,900 tons |
| viz., Rails | 189,200 ,, |
| Bars | 107,300 ,, |
| Plates and sheets | 28,400 ,, |

The author cannot indicate separately the output of acid Bessemer steel and of basic steel; but the statistics allow us to estimate at

about 143,000 tons, the quantity of basic steel contained in the 324,900 tons above stated. The producing power of basic steel in the French steelworks, as well as of acid Bessemer steel, is, however, much greater than would be supposed from the above figures. Indeed, although the official statistics indicate that some twenty-eight converters were at work in 1887, this only represents about two-thirds of the actually existing converters, which will number from forty-two to forty-four. Some Bessemer steelworks have been entirely idle in 1887, such as those of Terrenoire, Givors, Saint Nazaire, and Pagny on the Meuse; while some others worked with only a part of their plant.

*The Bessemer steel manufacture* was first introduced in France at Messrs. Jackson & Co.'s works at Saint-Seurin-on-l'Isle, near Bordeaux, and afterwards at Messrs. Petin, Gaudet, & Co.'s works at Assailly (Loire). It was afterwards developed in various districts, especially in the Centre, at the Imphy and Montluçon Works; in the Loire district, at the Terrenoire, Creusot, Saint Etienne, and Givors Works; and in the Gard district, at the Besseges Ironworks. The pig iron used by these works was made with mixtures of local ores and ores imported from Algiers and Spain, these last being somewhat dear, owing to the sea and railway freights. Hence the new steelworks, established during the last ten or twelve years, have been located in the closer neighbourhood of seaports, such as the Denain Steelworks (the first built), the Isbergues, Saint Nazaire, Boucau, and Beaucaire Steelworks, the first four being intended for using Spanish, and the last for Algerian ores.

The *Isbergues* Steelworks (Pas-de-Calais), belonging to the Acieries of France Company, are provided with two 8-ton American type converters, and are supplied with pig iron from two large blast furnaces. They announce their annual steel-producing power as 100,000 tons. These works exhibit their raw materials and their steels, classed in five categories, according to their hardness and mechanical properties. They have hitherto produced all kinds of steel rails, steel girders, blooms, and billets.

The Adour forges or Boucau Steelworks, near Bayonne, belonging to the "Acieriės dė la Marine et des Chemins de fer" Company, having two converters, also exhibit a ground-plan of their works, their raw materials, and their products, accompanied by

interesting analyses. They produce cast steel, distributed into fifteen numbers or classes, from the hardest to the softest. These works have also Siemens-Martin furnaces. They were established in 1883, specially for making steel rails, but since that time they have been obliged to look for other markets.

It is the same with the Denain Steelworks, which exhibit only their products in the special annex of the northern forges, and which possess also open-hearth furnaces.

The *manufacture of basic Bessemer steel*, or so-called *Thomas steel*, is effected in the four following works:—

| | | | | |
|---|---|---|---|---|
| Jœuf Steelworks, | 6 | converters, of together | 64 | tons capacity. |
| Longwy ,, | 3 | ,, | 45 | ,, |
| Valenciennes | 2 | ,, | 20 | ,, |
| Creusot ,, | 2 | ,, | 20 | ,, |

Adding the works in course of erection—Pagny-on-the-Meuse Steelworks, two converters, of together twenty tons capacity—the sum-total is fifteen converters, with an aggregate capacity of 169 tons, equal to about 500,000 tons of steel annually.

The three first steelworks are specially converting Meurthe and Moselle pigs, obtained from the local oolitic ores; the fourth (Creusot) converts pig iron made with its own oolitic Mazenay ores.

The Jœuf Works (Messrs. de Wendel) have not exhibited anything; the Creusot Works (Messrs. Schneider & Co.) have only exhibited their phosphoric mineral manures in the Agricultural Section.

The Longwy Steelworks make 250 to 300 tons of basic steel per day with their own pig (of which the composition is given above). They produce especially soft, very soft, and extra soft steels (No. 6, 7, 8 of the Longwy hardness scale), and also particularly extra soft steels (No. 9) for making wire, nails, &c. The breaking-stress for this last-named steel is less than 5000 pounds per square inch, and the elongation is more than 28 per cent. Its composition is given as follows:—

| | Per cent. |
|---|---|
| Carbon | 0·08 |
| Manganese | 0·25 to 0·30 |
| Sulphur | spur |
| Phosphorus | 0·03 to 0·05 |

These works are delivering to the trade blooms, billets, bars of every description, plates and rails, as also wire rods.

The North and East Steelworks, at Valenciennes, are also using basic pigs of the Meurthe and Moselle district, mixed sometimes with extra-phosphorus pigs, imported from Germany or from the North of England. They give the possible output of their two converters as 80,000 to 100,000 tons of basic steel annually. They sell rails, girders, bars, billets, and blooms, and their exhibits can be seen in the North of France special annexe.

The Stenay Iron and Steelworks, in the Meuse Department, are about the only works in France working their special process. They decarburise pig iron so as to obtain rolled or cast products into small (one ton or about) converters, according to the *Robert patented process.** Their exhibit includes numerous specimens of the products. Mr. G. Robert's converter shows in its horizontal cross-section the form of the letter D: the tuyeres, five or six in number, are horizontally situated nearer to the upper surface of the melted iron bath, in such a manner that the blast does not penetrate through the whole bath, but acts only on the superficial layer, communicating to it a gyratory motion, which brings every part of the bath successively in contact with the blast. Mr. Robert also, for certain stages of the process, slightly tilts the converter, so as to help this gradual conversion of the iron, and he declares that he can, with a much smaller or much cheaper plant than the ordinary Bessemer plant, produce at will hard, soft, and extra soft steels of superior quality, capable of being easily welded or run into moulds.

Mr. G. Robert exhibits numerous castings of great variety, some made with weldable steel. A Parisian foundry shop, with which Mr. Robert is also connected, produces steel castings obtained by his process, which he declares to have been introduced at some American and British works. Mr. Robert uses for his converter an acid or a basic lining, according to the material to be converted. So far as the author knows, the Stenay Works alone are just now working with small converters in France. Other processes, using also this class of apparatus, such as those of Messrs. Clapp and Griffiths, and others, have received trials in some French works, but the author cannot say what success they have obtained.

* See Mr. Garrison's paper on "The Robert-Bessemer Steel Process," p. 266.

## SECTION V.—MANUFACTURE OF STEEL IN OPEN-HEARTH FURNACES.

There were in 1877 fifty-one open-hearth furnaces in France. Their number appears to have decreased in 1887, owing to the closing of the Sireuil Works, in which Messrs. Martin were the pioneers of this new manufacture, and to the reduced working of the Terrenoire and Besseges works. The official statistics furnish the following data for 1887 :—

| | |
|---|---|
| Number of open-hearth furnaces in work | 69 |
| Output in 1887 | 143,764 tonnes. |
| viz., Rails | 13,709 ,, |
| Bars | 90,498 ,, |
| Plates and sheets | 39,557 ,, |

But the number of furnaces in working order in 1889 is notably greater, and may be estimated at about seventy-five furnaces of various systems and sizes.

Since the time of the introduction by Messrs. Martin of the new process in their Sireuil Works, the size of the open-hearth furnace has always been increasing. Instead of the 3 to 4 ton furnaces first used, 10-ton furnaces, 20-ton furnaces, and even, as in some steelworks of the Loire district, 35-ton furnaces can now be found.

In reference to *the manner of constructing* the furnace, the majority are of the fixed type—the so-called *Siemens-Martin furnace*, designed at first by the Messrs. Martin themselves, and having regenerators situated underneath the hearth, and the reversing valves on one of the small sides. In two or three steelworks only can the *Pernot furnaces* be found, with a revolving circular basin or hollow hearth, or the *Batho furnace*, with a round hearth, supported by an iron plate, free underneath, and round regenerators, with plate iron casing, placed laterally and above ground. But the use of these varieties of the open-hearth furnace does not seem to extend very much in the French steelworks which look as if they preferred the ordinary type. All these furnaces are heated by means of generator gases. Water gas and petroleum have not yet been tried in France for that purpose, so far as the author knows. The number of casts in twenty-four hours varies, according to the different works and types of furnaces, between two and four.

The most general *mode of working* is the *scrap process*. The *ore process* is not employed in France as far as the author knows, and the combined use of scrap and ore, as in the *Landore process*, is only in current practice at the Allevard Works, as far as the author can say.

The *nature of the lining* varies in the different works, and according to the description of materials used. Sometimes the lining is *acid*, that is, it is made with sand, ganister, or silicious puddle; sometimes it is *basic*—that is, made with magnesia bricks or puddle (according to the system patented in 1869 by Mr. Emile Muller), or with dolomitic bricks and blocks; at other times the lining is *neutral*—that is, made with chrome ore (according to the *Valton-Remaury process*). When the lining is made with chrome ore, Messrs. Valton and Remaury state that no material is taken from the lining either by the molten metal or by the slag, so that no corrosion takes place, and it becomes possible to act on the metal either by scrap, or by ores, or by various agents, in such a manner as to effect a complete dephosphorisation, and to produce various descriptions of steel. Messrs. Valton and Remaury exhibit drawings of furnaces neutrally lined, specimens of their chrome ore and linings, and products of some steelworks working their process. French steelworks, such as Fourchambault and Alais, for instance, choose the neutral lining rather than the basic one, which, they say, is sooner worn out, and above all when some iron ore is used in the process.

The *dephosphorising mode of working*, properly so-called, that is, the conversion of truly phosphoric pigs (such as those of Meurthe and Moselle) into cast steel by the open-hearth process, is not yet much used in France. This description of pig iron is sooner dephosphorised in the basic Bessemer converter. Mr. Fould-Dupont, however, shows in his beautiful exhibit (Central Gallery) cast steel of many different forms obtained in open-hearth furnaces from his Pompey pig iron.

On the other hand, in many steelworks, the basic or neutral lining is used for making open-hearth steel with ordinary pig and scrap, not free enough from phosphorus to yield good steel on an acid lining, and too low in phosphorus to be worked in the basic converter. Some of them are even working pure pig and scrap upon basic and neutral hearths, and produce soft and extra soft steels

of very high quality: these steels being, besides, either simply carbon steels, or steels into whose composition enter silicon, manganese, and chrome, inasmuch as the open-hearth furnace is a very convenient and readily adaptable one, which allows the easy introduction and stirring of any reagent in the metallic bath.

Upon the whole, the modes of working in the open-hearth furnace are very diversified in France, not only owing to the acid, basic, or neutral lining, but also owing to the composition of the materials—pig iron, scrap, ores, and alloys employed.

The Exhibition supplies the means of getting an idea of this fact, as the author will show by a brief examination of the principal exhibits.

The Firminy Steelworks, the first to work the Siemens-Martin process upon a commercial scale, have eight open-hearth furnaces with which they manufacture many different sorts of steel, from the armour-piercing shells, made with forged extra hard cast steel, to the weldable extra soft steels for wire, horse-shoe nails, mechanical, navy, and gunnery forgings, not forgetting the very numerous exhibited steel castings.

The Saint Chamond Steelworks exhibit sundry ingots (among which there is one of 100 tons) intended for heavy guns, large plates of various thicknesses made from ordinary or chrome steel, tubes for guns, axles, tyres, armour-piercing shells, other shells with large chambers inside for explosives, compound armour plates (wrought iron and steel), wire rods, and wire.

The works of Marrel Brothers, which contain four 35-ton furnaces, exhibit sets of tubes and hoops for heavy guns, a large compound armour plate, structural bars of many different forms and sizes, and an 86-ton steel ingot.

The Saint Etienne Steelworks produce steel tubes and guns, tyres, axles, plates made with carbon or chrome steel, castings, &c.

The Denain Steelworks are also manufacturing such diversified products as bars, plates, sheets or castings, and their exhibition is well worth examination.

The Chatillon-Commentry Company, at their Saint Jacques de Montluçon Steelworks, produce in the open-hearth, on a large scale, steel castings of every description, bars, tyres, axles, wire rods, shells, armour plates and *tubes*.

Some other steelworks, although of minor relative importance, have also interesting exhibits.

The Hennebont forges, in Brittany, show their extra soft steel, obtained on basic hearths and worked into sheets and tin plates, which they decorate in the finest style with pretty paintings, and which are used for making domestic and kitchen utensils, preserve boxes, &c.

The Montataire Works produce also open-hearth steel for sheets and tin plates.

The Valenciennes Steelworks exhibit tyres, axles, girders, and sundry bars made from Siemens-Martin steel.

The Ariége, Alais, Fourchambault, and Marnaval forges exhibit open-hearth steel of many different forms and sizes.

## SECTION VI.—MANUFACTURE OF BLISTER STEEL, AND OF CRUCIBLE CAST STEEL.

The use of *cementation* or *converting-furnaces* is somewhat stationary in France. There were in 1877 thirty-four converting-furnaces with an output of 1717 tons of blister steel; in 1889 the number of working furnaces was twenty-four and the output was 1491 tons.

These furnaces are not employed only for the carbonising of superior wrought iron bars, intended for the making of shear-steel or tool cast steel; they are also used for adding carbon to certain puddled steels and even to certain cast steels for special purposes.

In reference to *crucible steel*, the official statistics give, for 1877, 101 furnaces with an output of 7252 tons; and for 1887 only 39 furnaces (containing 501 crucibles) have produced 7532 tons. The old furnaces, heated by coke fires, and containing two or four crucibles each, are now to be found in a few inconsiderable works; the large steelworks employ actually nearly everywhere large gas Siemens-furnaces, containing twenty, and even forty crucibles.

The melting of crucible steel is not only employed for producing tool cast steel by the fusion of blister steel, or for making homogeneous iron by the fusion of pig iron with malleable iron. This mode of melting metals has now taken a prominent place in the

manufacture of the new steels, in which several substances besides carbon are alloyed with iron, as can be seen in the Exhibition by inspecting the Unieux, Assailly, and Firminy exhibits.

At Messrs. J. Holtzer & Co.'s, M. Brustlein began, many years ago, and has continued since, practical researches and experiments with a view to ascertain the influence of some metalloids (such as silicon), and of some metals (such as manganese, chromium, tungsten, and copper), on the mechanical properties and the qualities of cast steels. These trials brought him to the manufacture in crucibles of some iron alloys, like ferro-chromium and others. In 1878 the Unieux Steelworks exhibited ferro-chromium and chrome steels, which were much admired. In 1889 these works exhibit chromium carburets, silico-chromium, ferro-chromiums of various percentages, silico-ferro-chromium, and manganese-ferro-chromium—all these alloys being obtained in crucibles; and also a comparative series of different grades and kinds of steels, carbon steel, manganese steel, silico-manganese steel, copper steel, wolfram steel, chrome steel, and chrome wolfram steel. The author cannot here give details of the manufacture and the properties of these different steels, but he believes that they are well worth the attention of the members. Besides these, in some measure, theoretical exhibits, Messrs. Holtzer and Co. show many fractures of ingots, steel bars of different qualities, and steel castings of every description. They exhibit also their celebrated chrome steel shells (the first shells of this kind having been made by them in 1882), their chrome steel plates (up to two inches thick) intended for cuirass breast-plates, and for shields proof against musket and machine-gun shots.

The "Forges et Aciéries de la Marine" Company, which produce in their Boucau Ironworks ferro-chromiums up to 65 per cent. chromium, exhibit the crucible steels made in their Assailly Steelworks. There can be seen chrome steel, wolfram steel, and chrome-manganese steel, as also titanic steel and nickel steel, both in ingots and in bars, not forgetting chrome steel plates and shells for military purposes. The different manufacturing processes cannot naturally be described, but an inspection of the products will be interesting for the specialist.

The Firminy Steelworks Company manufacture chrome steel and other kinds of cast steel. Their armour-piercing shells and

steel castings, as well as their cast steel wires and piano-strings, are well worth attention.

The Chatillon-Commentry Company exhibit wolfram, chrome, and carbon crucible steels, and deliver to the trade very diversified products, from chrome steel plates and shells to piano-wires, as also very heavy steel castings.

Messrs. Marrel Brothers possess in their Rive-de-Gier Works an important crucible casting shop, and exhibit chrome steel shells, as well as their neighbours.

There are also some smaller works which have crucible casting shops for making tool steels, &c.

## Section VII.—Miscellanea.

After having thus briefly reviewed the different branches of French siderurgy, the author, before concluding these notes, will add some information in reference to the plant of certain French ironworks and some points of manufacture.

*Metallurgical plant.*—Messrs. Marrel Brothers are just now erecting in their works a very heavy steam hammer of which they exhibit a reduced model, and give the principal dimensions as follows:—

| | |
|---|---|
| Weight of the falling mass . . . . . . | 100 tons |
| Weight of the anvil block . . . . . . | 00 ,, |
| Maximum height of fall . . . . . . | 6 metres |
| Steam cylinder diameter . . . . . . | 2 ,, |

This steam hammer will be used with two 180-ton steam cranes, and two others of 50 tons each. It is to be established in a large shed, in which a 50-ton steam hammer is already working, along with 100-ton cranes. Messrs. Marrel Brothers exhibit large forgings, as, for instance, big cranked wrought iron shafts for large steamships, which prove both the power of the plant and the skill of the workmanship.

The Saint Chamond Steelworks possess a 100-ton steam hammer, which is used for the working of large ingots (one of those exhibited weighs 100 tons), intended for manufacturing heavy steel guns.

The Creusot Works exhibited in 1878 a model of its 80-ton steam hammer. Messrs. Schneider & Co. have not gone beyond

this size of steam hammer, and just now they are building, as well as the Chatillon-Commentry Company, high power hydraulic forging presses for armour plates and steel blocks. Their press is given as of 4000 tons. Many metallurgists prefer, for the working of steel ingots, the use of the press to that of the most powerful steam hammers; but the latter have still kept some partisans, as can be seen in the Exhibition.

As to *rolling mills*, in the 1867 Exhibition there was shown the powerful bi-universal reversing rolling mill exhibited by Messrs. Marrel Brothers, with rolls 3½ feet diameter and 11 feet of useful length, so constructed as to leave 3¾ feet clear space between themselves. This mill was intended for armour plate rolling. In 1889 the Chatillon-Commentry Company exhibit drawings of the most powerful rolling mill in France. Each roll weighs 30 tons, with about 13 ft. 4 ins. of useful length; the height between them can be increased to 6 feet. This mill is able to make plates 2 feet thick and 10½ feet long, weighing 40 tons. The mill is provided with a special patented arrangement, which allows of keeping horizontal the connecting spindles how distant soever may be the rolls, owing to the thickness of the ingots to be rolled. The pinion housing which realises this is exhibited in the "Metallurgical Gallery." It is made from steel castings, produced at Montluçon Saint Jacques, and some of them weigh more than 35 tons.

As to the rolling of very long steel bars for rails, girders, and billets, the North and East Steelworks Company have recently constructed a rolling mill, of which drawings are also exhibited. This powerful apparatus comprises on the same line three sets of 2-feet rolls, the blooming, the roughing-down, and the finishing ones, all making the same number of revolutions; it is driven direct by an horizontal reversing steam engine, with two steam cylinders 50 inches diameter and 56-inch stroke, able to make 150 revolutions per minute by developing 5000 horse-power. The mill is provided with live rollers on both sides, with a special hydraulic contrivance for carrying ingots, blooms, or bars from one groove to the following one, or from one set of rolls to another, as well as with an hydraulic rocker, which receives the ingots from the Gjers pits, and delivers them horizontally to the blooming rolls; and is served by several steam or hydraulic cranes, one of them

specially established for the service of a group of 16 Gjers pits. This mill, as well as its engine (which was constructed by the Cockerill Company), is well worth the attention of the visitors, owing to its many interesting features.

The visitors can see in the Metallurgical Gallery steel wire rod hoops of very great length (some more than 3000 feet long), which testify to being rolled in special mills. Some ironworks, indeed, possess rolling mills of great producing power, designed on the German type. These mills are capable of rapidly drawing soft steel billets, six to seven centimetres square, into No. 20 to No. 22 rods ($\frac{44}{10}$ to $\frac{54}{10}$ millim. diam.) by means of one or two sets of roughing rolls, making 200 to 225 revolutions per minute, and of seven or eight sets of finishing rolls, making 450 to 500 revolutions per minute, the motive-power being transmitted by hemp-ropes from a strong steam-engine. This engine is generally a compound one, with two horizontal cylinders, 28 inches and 42 inches diameter, 40-inch stroke, making 80 to 100 revolutions per minute. The Fourchambault Forge (Commentry-Fourchambault Company), which exhibits a steel-wire rod hoop, No. 21, among others, 202 kilog. weight and 1383 metres long, employs also a special rolling mill of another system (the *Bedson system*, as employed by Messrs. Richard Johnson & Nephew, Manchester).

In reference to *furnaces*, the author would state that several gas-firing systems of Siemens and others are in practical use in France, as well for heating ingots, piles, blooms, slabs, &c., as for melting metals. The Gjers pits are only operated in a few works: the cause being, perhaps, the notable decrease in the steel-rail manufacture during the last two or three years.

The visitors can see in the "Palais des Machines" a collection of Piat's portable oscillating crucible furnaces, with and without a movable hopper. These furnaces are rather used for melting copper and bronze alloys than for iron and steel. Mr. Piat has patented and exhibits a new form of furnace, which he styles the *cupola-crucible*, and which is intended for the benefit of founders of iron and steel alloys who cannot employ ordinary cupolas for the making of small castings. A special lifting contrivance allows, by means of a small windlass and balanced levers, without crane use, of the furnace being lifted high enough to allow of pouring metal into the ladle.

M. Hamelius exhibits a cupola, described as one *with total carbonic oxide combustion*, and showing another step in advance in the way opened up by the use of two horizontal rows of tuyeres in the Ireland and other cupolas.

*Metallurgical processes.*—In the preceding sections of his paper, the author has already reported on some new processes introduced in France during the last twelve years, such as the basic Thomas-Gilchrist process, and those of an analogous character, the Rollet process, and the G. Robert process especially. He does not think it necessary to return to these matters, and he only desires, by way of concluding these notes, to make some more general remarks.

The researches and the chemical studies relating to iron metallurgy have been numerous during some years past; they have not been unfruitful for the iron industry. The basic, or Thomas-Gilchrist, process is one of their fruits, the importance of which cannot be contested. Messrs. Thomas and Gilchrist have been induced to make trial of their basic linings, as they told the author in 1878, by the scientific writings of the late Professor Gruner. The Rollet process, the Valton-Remaury neutral lining, and others, can also justly be considered as results procured by the chemical laboratory.

Since the considerable increase of the new cast steel (Bessemer and Siemens-Martin) manufacture, these metals have been particularly studied by chemists, often associating themselves for that purpose with mechanical engineers, as can be seen by the writings of Mr. Deshayes on the relations between the mechanical properties of steel and its chemical composition.

But what appears to the author to characterise, above all, the scientific researches made in France on the metallurgy of iron during this period is the intervention of physical science in these researches. Metallurgists already knew the calorimetric studies of Messrs. Troost and Hautefeuille on the carburetted, siliconised, and manganesian pig irons. They possess now, among others, Mr. Forquignon's researches on malleable cast iron and steel, those of Mr. Pionchon on the calorific capacities and the physical changes of iron at high temperatures, the studies of Messrs. Osmond and Werth, engineers at the Creusot Works, on the intimate structure of steel; those of Mr. Osmond on the transmutations of iron and carbon in the malleable irons, steels, and white pigs; and in all

these works there have been used, at the same time, chemical analysis, calorimetry, microscopy, and even electrical measures. Visitors to the Exhibition can see in the Metallurgical Gallery an apparatus used in the Montluçon-Saint-Jacques Steelworks for studies of that kind—the Evrard apparatus, for ascertaining and measuring metal dilatations at high temperatures. Alongside of this apparatus will be found the Mesuré and Nouel pyrometric telescope, employed for ascertaining the temperature of incandescent bodies, and based on polarisation phenomena.

These various scientific studies have had an influence which is considerable over the French metallurgical works, although the author cannot possibly do more than allude to it. One of their results, and perhaps not the least important, is the considerable increase in the making and employment of steel castings in France, a fact which has forcibly impressed visitors to the Exhibition of 1889.

Forging, tempering, and annealing steel, and especially steel in large pieces, have made important progress. Tempering is no more now, as in former times, a process aiming only at the hardening of steel owing to a somewhat mysterious property. It has been made sufficiently clear, owing to the studies of Messrs. Osmond and Werth, especially undertaken in order to enable practical metallurgists to turn to profit the molecular changes effected in cast metals by more or less sudden temperature changes, resulting from various new tempering processes, as, for instance, tempering in refrigerant mixtures (Schneider's patent) or in molten lead (Montluçon-Saint-Jacques patented process). It is not now always hardness, formerly generally associated with brittleness, which is required and obtained from tempering; it is sometimes quite the contrary—that is to say, body and malleability.

## *DISCUSSION.*

Mr. P. C. GILCHRIST said he would not take up time by discussing the paper, which would be invaluable for reference, but he should like to make a remark with reference to a statement with regard to the experiments of his cousin, the late Mr. S. G. Thomas, and himself, in reference to basic linings. Those experiments were made before they had read the very valuable writings of Professor Gruner. He wished to take that opportunity of correcting what he had no doubt was an unintentional error, and the more so as Mr. Thomas was no longer with them to speak for himself.

Professor JORDAN said that when he saw Mr. Gilchrist in 1878, he quite understood that he and Mr. Thomas had read Professor Gruner's writings before the experiments were made. They were now given to understand that they had read those writings after the experiments had been begun. It was, no doubt, a misunderstanding on his part.

Sir LOWTHIAN BELL, Bart., said the members would no doubt agree with him in thinking that there might be some confusion in the exact chronology of the development of the invention under consideration. He thought that there could be no doubt that the honour belonged to M. Gruner of having first clearly dealt with the conditions which must obtain in order to remove phosphorus from pig iron. Of course, the announcement of the scientific truths upon which such an invention depended was very important; but in these cases, and particularly in the one in question, there was a long distance to travel between the mere announcement of a philosophical principle and its successful application. They had, in the first place, a subordinate difficulty connected with the process, but nevertheless an important one. This consisted in attaching the lining to the walls of the converter in such a manner as to make it durable; and for this he thought no one would dispute that the credit belonged to Mr. Riley. It was possible that *Professor Gruner*, if he had undertaken the

practical working of the process, might possibly have failed for want of the knowledge possessed by Mr. Riley. Then last, but not least, there was needed the application of considerable capital in order to bring the matter to a successful issue. Mr. Gilchrist and his late partner, Mr. Thomas, were fortunate in obtaining the assistance of Messrs. Bolckow, Vaughan, & Co., and the ready and valuable co-operation of Mr. Windsor Richards. Thus, however largely society might be indebted to M. Gruner for what he had done, undoubtedly, for the practical working of the system, the world was still more indebted to Mr. Snelus, Messrs. Thomas and Gilchrist, Mr. Riley, and, lastly, to the enterprise and perseverance of Messrs. Bolckow, Vaughan, & Co., for giving to the world a valuable contribution to metallurgical science. He expressed this opinion without wishing to detract in any way from the great service rendered in this direction by what had been done by one of the most scientific metallurgists of his day.

Mr. EDWARD RILEY said that Professor Williamson had proposed a basic lining at the meeting of the Institute at Swansea in 1870.

Sir LOWTHIAN BELL said that the date of Professor Gruner's exposition of the principle involved was 1867.

Professor JORDAN said, as it was a matter of history, he could not omit making a statement with regard to the basic process. The scientific ideas of Professor Gruner were first printed, he thought, in 1867. In 1869 a Parisian engineer made trials on a small scale with magnesian bricks, and two patents for dephosphorisation by means of basic linings in converters, or on the open-hearth, were taken out. He was about to have the linings tried at Le Creusot when the war began, but he was not able to find ironmasters disposed to carry it out; and, therefore, the basic process slept until Messrs. Thomas and Gilchrist discovered it some years afterwards. The experiments would perhaps have been made some eight years before if war had not broken out.

The PRESIDENT said, unless any other member desired to speak upon the paper, he would move that the best thanks of the

meeting be given to Professor Jordan for his communication. It had taken an immense amount of care and labour to prepare. It was a record of the progress of the iron and steel trades, and was historically a very valuable paper to be enrolled in the proceedings of their Institute. It was a paper which, he thought, would assist most materially in their examination of the products which were on view in the Exhibition, and would also instruct them, if they read it, as to what they ought to see in their excursions during the present week. They were deeply grateful to Professor Jordan. Some of them knew the immense amount of labour which he had devoted to the preparation of the paper, and he was sure that the members would accord to him their hearty thanks by acclamation.

A vote of thanks was then passed to Professor Jordan.

The PRESIDENT said the next paper to be read referred to the proposed Channel Bridge, and had been presented on behalf of Messrs. Schneider & Co. and M. Hersent. It was a matter of very great interest, and it was a great compliment to the Institute, that a project which had been so seriously studied as that had been should be presented to them. It foreshadowed the consumption of a million tons of iron and steel.

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The following paper was then read by the Secretary :—

# ON THE PROPOSED CHANNEL BRIDGE.

By Messrs. SCHNEIDER & Co., Creusot Iron Works, and H. HERSENT.

## PART I.

### I.—Introductory Notice.

The idea of connecting England with the Continent by a bridge is not new. It has from the beginning of this century occupied the minds of a great number of distinguished men, but the labours of M. Thomé de Gamond particularly contributed to render the idea popular.

Most of the schemes hitherto proposed have been insufficiently worked out.* They have all been found impossible to execute, and for this reason each has, in succession, sunk into oblivion.

A submarine tunnel was next thought of as a means of communication between France and England.

The advocates of the bridge, however, have once more given the subject their attention, and the object of the present paper is to show that the construction of a bridge between France and England may now be considered capable of realisation in practice. We may say that the problem is at present clearly placed before the technical authorities of both countries.

However gigantic the undertaking, the many and various improvements which have been made in the art of bridge-building fully warrant every hope of success in an attempt to build spans of metal, 500 metres in length, across the Channel, supported by columns resting at different depths on the bottom of the sea.

The metal it is proposed to use is steel. The extensive use that has lately been made of this metal, both in France and elsewhere, notably in the Forth Bridge, which is the outcome of the unmistakable progress of metallurgy, removes every doubt as to the feasibility of dispensing with about fifty per cent. in weight by the use of steel, without endangering the safety of the structure.

* The technical details and estimates have been worked out in conjunction with Messrs. Sir John Fowler and B. Baker, chief engineers of the Forth Bridge.

The preliminary projects submitted by MM. H. Hersent, Schneider & Co., and Messrs. Sir John Fowler and B. Baker, consist of separate reports relating respectively to the foundations for the piers to be erected in the sea, and to the construction of the superstructure, as well as of a rational statement of the means for placing in position the foundations and spans. The authors of these preliminary sketches do not, however, wish to be understood as thinking that no useful alterations can be made in their work when the time comes for the ultimate plans to be proceeded with. Whatever opinion may be formed of these projects, and whatever may be their eventual fate, their authors will at least have the gratification of having paved the way towards an undertaking of public interest, and of having furnished data sufficiently minute and correct to enable the scheme to be submitted to the judgment and criticism of competent persons whose careful attention they solicit. Among the great undertakings which present a certain analogy to the proposed Channel bridge, such as the opening of maritime canals, railways, ports, &c., none is to the same degree worthy, either of the international interest which has guided the promoters of this great undertaking, or of the direct interest of the two countries which will not only be called upon to bear the cost, but will reap the advantages of the project as well. The amount of metal and machinery to be provided for the construction of a bridge over the Channel would represent an aggregate weight of about 1,000,000 tons. The assumption is that each country will have to supply one half of this amount, which, on either side, would for a lengthy period give a powerful impulse to the development of national industry. To estimate as precisely as possible the expense entailed by the construction of the Channel bridge, it would be necessary to go further into the calculations, and to alter, if necessary, after duly consulting the maritime interests involved in the question, the number of spans of 500 metres, as well as of the spans of shorter length required in various places. In the same way the extensions to be made in the port of Ambleteuse, and in an English port situated equally near to the bridge, will have to form the subject of a more detailed inquiry.

An approximate idea, however, as far as it can be possibly

formed by a rough calculation at first sight, assuming that the arrangement of spans shown in the plan is adopted, permits the following estimate of cost to be given with reasonable certainty:—

Fr.380,000,000 for masonry supports, and Fr.480,000,000 for the metallic superstructure—in all, Fr.860,000,000, or £34,400,000.*

The works for the tunnel and the railways in both countries would have to be planned later on, in agreement with the companies whose lines would lead up to the bridge. The time required for the completion of the undertaking may be fixed at about ten years.

## II.—GENERAL DESCRIPTION OF THE BRIDGE.

### § 1. Situation.

The situation which seems preferable for a bridge connecting England with the Continent is, as it were, suggested by Nature herself, namely, the line stretching over the shallowest parts of the Channel, and connecting the shores where they are closest to each other. This line commences at a point near to Cape Grisnez, and reaches the coast of England near Folkestone, passing over the banks of Colbart and Varne. The adoption of this line would enable the existence of these two banks to be taken advantage of, so as to avoid working in great depths, and thereby diminish the height of the piers to be erected.

The banks are situated near the centre of the Channel about six kilometres apart. The depth of the water at that point does not exceed seven or eight metres at low water, and they are separated from each other by a depression about 25 to 27 metres deep. Between the banks of the Varne and the British coast the depth does not exceed 29 metres, but between that of Colbart and the Cranaux-Oeufs the bottom sinks somewhat abruptly down to 40 metres; it then attains 55 metres about midway across, when it begins gradually to rise. In these parts, then, the chief difficulties would be encountered in laying the foundations.

The sketch submitted gives about the shortest distance available for the ready connection of the existing lines of railway in both countries, without difficulty or an unusual amount of work.

* Converting the franc at 10d.

## § 2. Supporting Piers of Masonry.

*Preliminary Project by H. Hersent.*

In considering the construction of the supports, the nature of the bottom was the first thing that demanded attention, as it was necessary to ascertain whether its formation and resistance would be sufficient to ensure the stability of the structure; the next thing to be considered was the form to be given to the supports, so as to obtain as large a surface as possible at the base, without causing trouble from the effect of the ebb and flow of the tides; and lastly, it was found necessary to anticipate the difficulties that may be encountered in an undertaking of this nature in order to determine the measures to be taken for successfully grappling with them.

The result of repeated experiments is that the ground is found to be sufficiently solid to support very extensive works. In addition, the borings lately made in connection with the proposed Channel tunnel have confirmed the results of the preceding experiments as to the position and nature of the bottom, as published by M. Thomé de Gamond. More precise inquiries will be necessary when the works are proceeded with, as regards each pier, in order to be in a position to settle each detail beforehand.

At present, however, there is no doubt that the ground is capable of supporting a load of from 10 to 12 kilogrammes per square centimetre, as is often found to be the case on a foundation less solid than that afforded by the white and blue chalk which everywhere forms the Channel bottom. The soft parts of the surface in contact with the water and the strata of sediment and sand that may cover the bottom at certain points, especially near the shores, will have to be removed in order to lay the piers on more solid foundations. Each supporting pier will consist of a block of masonry of good material, set with Portland cement mortar, and laid on the sea bottom; their surface above high-water level will form the foundation for the metal columns which serve as direct supports of the spans of the bridge, and will measure 650 square metres. They will, moreover, have a batter of about 1 in 10 up to the top of the foundation caisson, which is flanged in order

to increase the surface of the base in contact with the surface of the ground.

The section of the piers will form a rectangle, 25 metres in length, and their width will have to be suited to each system of columns. This rectangle will terminate in semicircles, so as to oppose the least possible resistance to the currents.

Supposing 55 metres to be the length of the piers, the surface of the base of the piers in contact with the ground will be 1604 square metres. Where the depth is less, the surface will be proportionately smaller. Up to a certain height, the masonry will cover the whole surface of the base, while higher up two pockets will be provided in order to decrease the load upon the foundation, the sections of the walls being of sufficient strength to resist any additional loads. The masonry will be built inside metal caissons, similar to those used for ordinary bridge piers, and they will be sunk by the pneumatic process. These caissons, which will terminate in metal collars to secure the masonry, will be floated out to the spot where they are to be grounded. This will enable the ground to be carefully cleaned, and promote the application of the concrete that is to be interposed between the masonry and the bottom, as will be explained further on.

The caisson will, moreover, be surmounted by a movable dome, which will be removed when the upper part of the column is completed, so as to enable the masonry to be carefully finished with squared stones above the level of low water. Special arrangements will be made for anchoring the columns in the masonry, so that the anchorages may be at all times readily inspected in order to ascertain whether anything is out of order in each separate portion of the work. The whole of the piers will occupy a little over one-twelfth of the section of the Channel. This reduction of the section of the Channel is not likely to exercise a notable influence on the erosion of the bottom, or to bring about an appreciable increase of the speed of the flood and ebb tides. The distance between the piers, fixed at 500 and 300 metres for the large spans, will not be less than 200 and 100 metres respectively for the small ones, and will, at all events, be sufficient to prevent their proving an obstacle to the free navigation of sailing vessels. As regards steamships, no such danger is to be apprehended. The current, which

would certainly become a little faster in the centre of the openings, would carry floating bodies, even disabled vessels, towards that part, and prevent their ever touching the bridge.

It may, therefore, be reasonably admitted that, owing to these distances and dimensions, the piers would in no way modify the conditions of navigation in the Channel, and would certainly not constitute an appreciable obstacle to navigation in general.

### § 3. The Metallic Superstructure.

*Preliminary Project by Messrs. Schneider & Co.*

The metal columns are firmly placed upon the supporting piers of masonry. They are of a cylindrical shape, and will vary in height between 40 metres and 42·780. On these will be placed the main girders of the bridge. There will thus be between the lower part of the beams and the level of the sea at low water, a free space, varying in height between 61 metres and 63·780, which height, at high water, will be reduced to 54 metres and 56·780 metres, respectively. This height is amply sufficient for the passage of vessels of whatsoever description or tonnage. By placing the flooring upon vertical cylindrical columns, the space above indicated, of a minimum height of 54 metres, is kept throughout the whole of the span—a result which has not been achieved in the bridge of similar dimensions that is now being constructed over the Forth estuary.

In the Forth bridge, in fact, the height at the centre of the structure above the high-water level is 45·60 metres, but this height does not extend beyond the central third of the span. At the two-thirds near the ends this height greatly diminishes, until it is actually reduced to a height of scarcely 15 metres near the pier.

In order to consult the exigencies of navigation as far as possible, and to carry out economically the preparatory works, three different lengths of span have been proposed.

| | | | | | | |
|---|---|---|---|---|---|---|
| No. 1. | Alternate | spans of | 300 | and | 500 | metres. |
| No. 2. | " | " | 200 | ,, | 350 | " |
| No. 3. | " | " | 100 | ,, | 250 | " |

The longest spans correspond to the greatest depths, the smallest to the most elevated parts of the sea-bottom and to the parts near the shores.

The system of girders to be employed is that of simple, unlatticed beams, so as to ensure the proper distribution of all stresses. The secondary beams provided are intended to reduce the length of certain members, to prevent buckling of tension members, and to give all members in compression proportions suitable to the lengths concerned, whereby it becomes possible to leave the co-efficient of compression, which would increase the weight, out of consideration.

The level of the permanent way is 72 metres above the low-water level. This height might have been reduced by arranging the permanent way in the lower portion of the bridge, but in that case it would have been necessary to make the cross-beams a great deal longer, and, consequently, heavier.

By raising the permanent way, on the contrary, as it is proposed here to do, a marked economy is attainable, which will certainly not be absorbed by any increased expense involved by the necessity of erecting viaducts at both ends of the bridge.

There will be a double set of rails, and the width of the flooring proper will be 8 metres.

The whole width of the bridge is variable. The greatest distance between the axes of the main girders is 25 metres, such a space being necessary to ensure the stability of the structure under the action of violent gusts of wind. The roadways are of the ordinary width of 1·50 metres between the rails. The latter will be set in grooves to obviate accidents. The floor, made of ribbed sheet iron, is to cover the bridge throughout its length, so as to make every part accessible to the men appointed for the supervision of the bridge. Between and outside the lines of rails, platforms are provided for the men to stand on, and thus keep out of the way of passing trains. Upon the flooring it will be possible to establish "refuges," stations for the guards, signal-boxes, switches, &c. All these arrangements may be multiplied according to the requirements of the traffic, and placed at any convenient points on the spans. On the piers, lighthouses may be erected, to indicate obstacles to be avoided. The various kinds of lights used in lighthouses may also serve to indicate to shippers the distance from the Colbart and the Varne banks. It would have been easy to establish a bridge with four lines of rails instead of two, but the probable development of the traffic did not appear to warrant any

increase of outlay in that direction. The provision of a road for ordinary vehicles is also superfluous, as goods will always be carried by rail.

To meet objections from a military point of view, arrangements could be made for making the span at either end of the bridge unfit for use; the two end spans notably, which are in contact with the abutments, might be removable or made to revolve. A detailed description of the plans and methods of construction it is proposed to adopt, forms the subject of the following chapters.

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## PART II.

### FOUNDATIONS.

*H. Hersent's Preliminary Project.*

## III.—DETAILED DESCRIPTION OF THE FOUNDATION WORKS.

### § 1. THE SITUATION AND DIMENSIONS OF THE BRICKWORK SUPPORTING COLUMNS.

The ground affording sufficient resistance to safely support the piers when loaded, the surface of the bases has been so calculated that the foundation should not have a greater load than about 10 kilogrammes to the square centimetre. With regard to the piers sunk at 55 metres under the low-water level, the dimensions, the calculations of the masonry sections, and the corresponding weights per centimetre are summed up in the following table:—

| | |
|---|---|
| Length at base | 57,00m |
| " at low-water level | 47,50m |
| " above the cornice | 42,00 |
| Width at base | 32,00 |
| " at low-water level | 22,50 |
| " above the cornice | 17,00 |
| Surface at base | 1,604m$^2$ |
| " at low-water level | 960m$^2$ |
| " above the cornice | 651m$^2$ |
| Volume (exterior) | 86,000m$^3$ |
| " of the recess | 28,000m$^3$ |
| " of the masonry | 57,200m$^3$ |
| Loads to be supported per square centimetre at base on ground | 9,80 |
| " at low-water level (on the masonry) | 5,75 |
| " at base of columns *(on hewn granite)* | 8,20 |

These resistances offer every appearance of safety, alike as regards the ground, the ordinary masonry, the body of the pier, and the granite blocks supporting the metal columns. The base appears to be sufficient to resist the different transverse and longitudinal stresses (of which wind is the most important cause) that may tend to overturn the piers.

The length of the spans supported by the columns is 400 metres.

The surface exposed to the action of the wind on this distance is about 7590 square metres.

The surface exposed to the action of the wind on the metal columns, 622 square metres.

The surface exposed on the 20-metre sub-basement, 370 square metres.

The surface exposed on the lower part of the piers, 1570 square metres.

Assuming that the force of the wind, and the strength of the pressure exercised by the currents, attain altogether 270 kilos. per square metre, the stresses produced upon each of these surfaces will be as follows:—

$$
\begin{aligned}
7{\cdot}590\text{m}^2 \times 270\text{k} &= 2{,}049{,}300 \text{ ks.}\\
622\text{m}^2 \times 270\text{k} &= 167{,}940 \text{ ks.}\\
370\text{m}^2 \times 270\text{k} &= 99{,}900 \text{ ks.}\\
1{\cdot}570\text{m}^2 \times 270\text{k} &= 423{,}900 \text{ ks.}
\end{aligned}
$$

And the moments of overturn will be—

| | | |
|---|---|---|
| 2,049,300k × 137·1m = | 280,959,030 ks. |
| 167,940k × 95·4m = | 16,021,476 ks. |
| 99,900k × 66m = | 6,593,400 ks. |
| 423,900 × 28m = | 11,869,200 ks. |
| Total moment of overturn at the base of the piers . . . | 315,443,106 |

| | |
|---|---|
| One length of span of 400 metres weighs . . . . | 1,164,000 ks. |
| Two metal columns . . . . . . . . . . | 2,010,000 ks. |
| One masonry pier . . . . . . . . . . | 148,675,000 ks. |
| Total weight . . . . . . . . . . . | 151,849,000 |

The point of emergence of the resultant $x$ from the centre of the pier is

$$x = \frac{315{,}443{,}106}{157{,}849{,}000} = 1{\cdot}99\text{m}.$$

The surface of a column is 1604 square metres. The moment of inertia of $s$ in relation to the small axis of the column is 355,346.

$$\text{Hence } r^2 = \frac{355{,}346}{1{,}604} = 221{\cdot}5 \text{ m.}$$

One-half length $n$ of the columns is 28·5 metres.

$$\text{Hence } \frac{r^2}{u} = d = \frac{221{,}5}{28{,}5} = 777 \text{ m.}$$

The co-efficient of stability, that is, the ratio of the moment of overturn at the base of the piers to the moment that would cause a strain equal to zero on the side exposed to the wind, will be

$$\frac{d}{x} = \frac{7{\cdot}77}{1{\cdot}99} = 3{\cdot}90.$$

Each pier will consist of a block of good material, with two pockets or recesses to diminish the load on the base. The particular portion upon which the metal columns rest will be the same in all the piers, but the lower portion will increase in surface in proportion to the depth to which the structure is to be immersed in water.

The external walls will have a batter of 1 in 10, and the lower part, which will consist of a metal caisson, will project as shown in the plan.

Caissons.—The metal caisson of each pillar will correspond in external shape and dimensions to the contemplated depth of the foundations. It will consist of two distinct parts. The lower part will be two metres high, and open at the base, while the upper one, the exterior of which will surround the masonry of the body of the pier, will form one single chamber, extending over the whole surface of the caisson. Bracings and cross-girders will serve to maintain the sheet-iron casings in position, and in a state of rigidity.

The lower portion, intended for the use of compressed air, and for fixing the structure to the ground, will consist of an external skin, and of vertical walls, dividing the bottom into air locks with a surface of from 50 to 60 square metres each—these air locks, which are capable of being used either separately or together, with compressed air, and are intended for clearing the ground of foreign matter, or simply to level it, and to effect the final filling

at the junction of the structure with the ground. Each of these air locks will be provided with sluice valves arranged at the bottom, and with special devices for facilitating access and inspection, for removing excavated matter, and for filling up the excavations with concrete.

The first piers on each shore may be constructed without necessitating any alteration in the means ordinarily employed for this kind of structure. The experience acquired in sinking these first piers will thus enable improved methods to be adopted for the thorough clearance of the soil, the filling of the compartments, and, in short, the completion of the whole base in the case of depths exceeding 20 to 25 metres below the surface of the water. Hitherto foundations laid by the pneumatic process have scarcely ever exceeded 20 to 25 metres below the surface of the water. In exceptional cases they have reached 30 and above 35 metres, but at such depths accidents have sometimes occurred, which appear to have been the result of excessive fatigue on the part of the men employed, and of the want of proper provisions for arranging the air supply.

Divers going down in search of sponges and corals descend to a depth of 50 metres, and thus experience the effects of the compression and expansion which would be obtained in using compressed air at such a depth. It will not be too much, therefore, to say that the ground will be capable of being inspected under all the piers before the concrete is filled in at the base.

It may also be taken for granted that the bottom can be cleared beforehand by means of special apparatus, enabling compressed air to be dispensed with, and that the filling of the compartments and air chambers can be effected, either outside or inside the pillars, without its being necessary for the men to perform any important work below.

In considering the matter from this point of view, the question arises as to what would happen if the 120 cubic metres of concrete required for filling one compartment were conveyed down through a funnel pipe. It was found that if the water contained in the lower working chamber could be ejected to make room for the concrete, the filling of that chamber could be satisfactorily completed, and the concrete will in no way be inferior than in any of the other

methods used for ordinary depths. This method of carrying down concrete through one continuous pipe is far preferable to the use of cases, which are liable to give off rather considerable quantities of grout. From these remarks it may be inferred that if each compartment was filled in specially and separately from the others, the satisfactory completion of the work would be assured, and that, should any of the compartments not prove quite faultless in some respects, the whole of the work would not on that account be impaired.

These arrangements contemplated for the filling of the compartments have made it possible to determine the shape of the lower portion of the caissons of the piers, and the lines of resistance of the stiffening. The caissons would have to consist of one externally inclined wall or skin, and of vertical walls strongly braced at the part that is in contact with the ground, and terminating in cutters. All these vertical walls should join the metal roof that separates the lower compartments from the upper part, and correspond to the girders above, whose resistance they will thus increase. When the load is sufficiently heavy the declivities will touch the ground, and this contact, at the time of low tide, taken in conjunction with the normal oscillation, will probably be sufficient to break off fragments, which the currents of the sea will remove when high tide sets in. The chances are that the levelling of the ground can be done without any considerable expenditure of labour; but the cutters will have to be of rather considerable size, in determining which the experience acquired by the sinking of the first caissons near the shore will have to be taken into account. The levelling apparatus used in the ports of Brest and Cherbourg has already furnished valuable hints on this point.

The portion of the caisson situated above the roof will serve to contain the masonry, and to protect the same from immediate contact with the water, while at the same time it will enable the masonry to be built up as the caisson sinks.

This part of each caisson will be formed of a water-tight metal case, stiffened vertically and horizontally. All these stiffenings will be enclosed in the masonry, which, in the possible event of the decay of the iron, would remain *still* unaffected.

The part of each caisson situated above the level of low water will be movable, and can be utilised successively for several piers, and it will consist of a sort of dome composed of metal plates suitably fitted together. These will cover the structure of the pier, and enable the lower ends to be sunk to the sea bottom in such a way that the masonry, although floating, can be completed as if it were erected on land. This has been successfully achieved in building the dry docks at Sargon and Missiessy, at Toulon, where 45,000 cubic metres of masonry, representing a weight of 100,000 tons, were kept afloat in the caissons for several months.

The piers, at a depth of 55 metres, would have to support the load of 12,000 tons at their juncture with the ground, which is by no means an unheard-of achievement.

Plans 3, 4, and 5 illustrate the general arrangement of the caissons; they show the lower portion, or concrete chamber, the central portion containing the ballast masonry, and the top or dome that is to surmount the whole.*

MASONRY.—The masonry of which the body of each pier is to consist should be set with good homogeneous calcareous materials from Marquise, Boulogne, &c., of which there is a great quantity in the neighbourhood of Gris-nez. The materials can be carried to the spot either from Ambleteuse, Boulogne, or Calais, and will cause no trouble.

The mortar required for the whole structure should consist of Portland cement, in the proportion of 500 kilogrammes per cubic metre of silicious or granitic sand. Calcareous or schistose sand must be avoided, as liable to decomposition. Upon the floor of the caissons a layer of concrete 1·50 to 2 metres thick is to be formed to protect the iron stiffening beams, and above that the ordinary masonry shall be laid of rough quarry stones, which shall rise up to the low-water level, two pockets being left which will render the structure lighter, and will greatly facilitate the work on the lower portion, when it is required to fill the chambers. At each successive height of about 4 metres, two courses of dressed stones will be placed, which will have the effect of better distributing the load, and rendering the tendency to settle down more uniform. The level surface of the lower portion below the low-water level should also consist of rough stones. From the low-water level

* *These plans may be consulted at the Offices of the Institute.—*ED.

upwards, the pockets before mentioned will gradually be made narrower, and terminate in two shafts, giving access for purposes of inspection and for anchoring the metal columns. The masonry and the upper part below the low-water level should be fitted with granite stone walls, so as to offer a considerable resistance to the crushing stress and to atmospheric destructive agencies. The platform upon which the metal columns and supports of the bridge are to rest should consist of a number of successive courses of granite stones, which should distribute the weight and the loads equally over the surface of the piers, and they should be provided with the necessary holes for anchoring the metal columns to the pillars. Round the platform a metal balustrade should be erected to protect the persons employed in supervision and repairs.

## § 2.—The Construction, Conveyance, and Fitting into Position of the Piers.

The Port.—The size of the pillars, and the considerable amount of material required, will necessitate the establishment of a port at a point near to the spot where the works are begun on either coast. On the French coast, a great construction of that sort would probably have to be provided for in the Bay of Ambleteuse, although part of the traffic will still have to be left to the ports of Boulogne and Calais. On the English coast, Folkestone would form the centre of operations. The port of Ambleteuse might be established in the free part of the valley, and may be protected by means of two piers or jetties. The west pier would point to the north at an angle of 45 degrees to the coast, and the north one would form an incline southwards. The entrance would be 250 metres wide, and 7 or 8 metres deep at low water.

A channel, 150 metres wide, protected by a stockade of wood forming a quay for the vessels to come alongside, would give ready access to the new port, which would practically consist of the existing port, deepened and extended.

This port, dug 6 metres deep below the low-water level, would

be 700 metres long and 350 metres wide, so as to admit of the plant necessary for the simultaneous construction of a number of girders. The bottom would be utilised for constructing the foundation of the caissons. Several docks would have to be provided in the port at half-tide level or somewhat lower, which would be isolated from each other, and separated from the sea by floating dams, after the manner of floating docks, that would have to be operated whenever the caisson is taken out, so as to simplify this operation as much as possible. Besides the port, a tidal dock would have to be constructed, with quays, bridges, and all necessary arrangements for facilitating the embarking of men and goods, and for ensuring the safety of the floating stock. The northern railway lines would have to lead up to the quays, and to any other points that may be deemed desirable, so as to enable all the material and machinery to be carried from place to place by railway, and in order to facilitating the loading, unloading, and the storage of same.

The dwellings of the workmen should be established near at hand, but it is very probable that the steam-ship traffic would permit of the employment of workmen residing in Calais or Boulogne, especially at the works to be performed in the offing. It is, moreover, very likely that important quantities of material would have to be conveyed by these ports. This division of labour on the French coast would benefit the whole of the operations, and prevent obstruction at any point of the district occupied by the works. On the coast of England, the port of Folkestone and others would be made use of for similar purposes. A network of telephonic cables should connect the different loading stations between them, and also with the yards on land and in the offing, so as to ensure that unity of action which is absolutely necessary in the execution of great undertakings such as this. The first portion of the foundation caissons, which includes the lower chambers, and the cross-beams up to a height of 3·50 metres to 4 metres, will be constructed in a closed basin, as has been done with the caissons built in Toulon, Antwerp, and Saigun. They will be afloated by opening the doors at the spring-tide, so that they may be brought up to the outer harbour, where the work will be continued.

In the outer harbour the erection of the metal walls and the

caissons will be carried on until a height of from 12 to 15 metres above the base is reached. At the same time the ballasting, by means of a layer of concrete from 2 metres to 2·50 thick, will be commenced, being intended to insure the necessary stability for conveyance through deep water. This latter operation can be carried out by means of tugs when the caisson is sunk 10 or 12 metres deep, that being the maximum weight that can be charged, lest it should be found difficult to leave the port. The caisson will then, with its ballast of masonry, be brought to the place it will have to occupy, where it will be fixed by the means hereafter described. The ground will be excavated by the ordinary methods, with the aid of compressed air and other suitable means, until the base is firmly established upon a sufficiently firm foundation. The chambers on the roof will be filled with concrete, and the upper masonry will thus gradually rise until its completion. As regards the pillars to be sunk at a depth of less than 10 or 12 metres below low-water level, the operation will be as described, but beyond that depth the caisson, when it leaves the port, will be brought up to the pillar that is already placed in position, and the ballasting will be continued up to the time that it has to be taken to the place of its immersion, so as to concentrate as far as possible, at one and the same place, the whole work to be performed in the sea, and thus facilitate surveillance and measures of precaution that cannot be dispensed with in such operations.

By thus proceeding step by step, the necessary experience will be acquired as the work goes on for venturing down to lower depths, the work being perfectly regular, and, we may say, even normal, since it is supported by precedent.

Placing of the Piers.—The most important, and perhaps the most delicate, operation in this great undertaking is the placing of the piers, while still afloat, in the positions they are eventually to occupy, with sufficient precision, so that the length of each span of the superstructure may be about equal. Great precautions must evidently be taken, and the effects of bad weather avoided, until sufficient experience has been acquired.

For the first operations, it will always be necessary to work in fair weather and at low water, preferably slack water, so as to be able to touch the ground *and fix the* construction in a short time.

If, after inspection, it should be found that the place where they ground is not the right one, the piers will have to be raised, and the whole process gone through over again, until the column is in its proper place. In fact, the method to be adopted is very similar to that which we used with M. Castor for putting in place the piers of the Arles bridge over the Rhone.

At a distance of from 200 to 300 metres from one another, strong anchors would be run out attached by chains to a number of barges supporting and raising them. These barges will be connected with the caisson of the pier by sufficiently strong lashings to enable it to be retained in its place, to line it out, and to determine the distances, all of them operations requiring the attendance of very experienced engineers, capable of duly taking into account the deviations due to the action of the tides. The putting into line and fixing of the distances may be effected when the bottom of the caisson is at a short distance from the ground (say from ·50 to 1 metre). It will thus be possible to admit into the chambers in the lower portion of the masonry an amount of water that will give the caissons sufficient weight to enable them to touch the ground, and to insure stability, which would make it more easy to ascertain whether they are placed in the right position, and are perfectly vertical.

Whenever it might be found that a pier was not in its proper position, it would be necessary, in order to get it afloat again, to remove the water, to fill the air locks with compressed air, and to begin the same operation afresh. If, on the contrary, the operation proved successful, it will be sufficient, in order to ensure the stability of the caisson, to add to the load a certain amount of masonry, and to withdraw the water or compressed air which had been used during the provisional loading, preliminary to placing the pier in position.

The position of a pier sunk in the midst of anchored barges, and attached by the necessary moorings, would be very similar to that of a spider in the middle of its web.

By reason of the particular position which each pier would take up, it would probably be necessary to strengthen some of the moorings, and to run out several more anchors.

The barges used for that purpose will have to be provided with

the necessary steam-engines and winches, so as to operate with the necessary amount of safety and power. The same winches can also be used for lifting the anchors.

The barges will form a sort of protecting belt to the pier they surround at the moment of its immersion, and will serve to moderate the height and strength of the waves. It will be possible even to increase this effect of allaying the waves by using open rafts, moored to the barges, which would cover a comparatively large surface of water on the weather side.

The employment of oil, as has been pointed out by M. Admiral Cloné, has the effect of stopping the breakers, and it is very probable that, after a few experiments, we might, in this way, succeed in obtaining sufficiently smooth water around the piers to enable the structural parts to be placed in position under almost any conditions of weather.

The experience hitherto obtained of the means of protection against the action of the sea, shows that one may succeed in working, almost without interruption, at floating caissons, as if they were situated on a small island. Such is the impression which has been deeply engraved upon the memory of all those who witnessed the works carried out in constructing the docks in the port of Toulon. When the moorings are thus arranged near the position of the columns, the masonry of the pier will be built up, the lashings being at the same time tightened, in order to avoid having too much to do at the last moment. The laying of the masonry will compel the continuous raising of the metallic walls or skirt of the caisson up to the level of the sea at low water.

For the purpose of protecting the masonry, after getting each column into position, and bringing the upper portions of the masonry into correct line, the caisson will be surmounted by a movable metal structure, which we may call a dome, on account of its being contracted towards the top.

This dome, which will be about 14 metres in height above the fixed portions of the caisson, will be composed of metal plates bolted together to the top of the wall or skin of the caisson, in order to permit of subsequent taking to pieces. The tightness of the joints will be produced by layers of caoutchouc, as is usually done with dams 80 to 100 metres square surface,

weighing 80 to 20 tons, employed in foundation caissons. The mounting and taking to pieces of this dome will be effected by means of a floating derrick, capable of lifting a weight of from 40 to 50 tons.

The lower part of the dome will be furnished with a gallery, or horizontal platform, which will be used at the same time for the purpose of increasing the general stability. In the middle part there will be another platform or gallery, above high-water mark, for receiving the cranes necessary for lifting the materials required for the masonry, after the caisson has been finally placed in position.

LEVELLING THE GROUND.—Before the caissons are put in place, it will be easy to ascertain, by preliminary boring, the nature of the ground upon which the pier would have to rest, and to see whether it is perfectly horizontal or not. These experiments will also permit of making sure that the ground has sufficient resistance to sustain the piers, or whether it is necessary to prepare a special bed for them. Such levelling of the bed will probably be requisite in the case of piers near the coast, but owing to the small depth of the sea in those parts, the pneumatic process may be used without any difficulty. For depths of from 20 to 35 metres, which hitherto have only been obtained in exceptional cases, no uneasiness need be felt with regard to the applicability of compressed air, inasmuch as experience will show the practical improvements that may be made in the methods and means already employed.

About twenty-four piers will have to be erected in portions of the ground lying at a depth exceeding 35 metres. For these twenty-four piers, the experience previously acquired cannot fail to prove a safe guide as to the improvements that may be made in the methods of operation, and to give practical value to works which hitherto have only been attempted in cases of exceptional difficulty.

Should it so happen that, in levelling the ground for the piers that are to descend to the maximum depth, any danger need be apprehended from the use of compressed air, there will be no necessity, nevertheless, to remain inactive, for owing to its special structure the ground can be acted upon by means of rotating machinery that can be set in motion from the platform, or it may

be cleared and levelled beforehand by means of special machinery. The clearing of all matter rejected in the levelling operation can be performed by means of force-pumps of considerable power, or compressed air engines, whereby the ground operated upon would be divided into a number of sections, so as to enable the currents to carry away the fragments. Experience will probably show that the action of the hydraulic jet under pressure will alone be sufficient to clear the ground, and especially to remove all that is on the surface.

The filling of the working chambers with concrete will be effected by means of compressed air, in the case of all the piers that will allow of compressed air being used. There is no doubt that this very important operation will itself suggest various possible improvements in the processes now employed, and will meet all requirements in the sinking of most of the piers.

Filling in the Concrete at the Base.—It is thought that by repeating the experiments made in the construction of the Kehl Bridge, it will be possible, in the case of great depths, to convey the concrete down to the lower parts of the working chambers or air locks by the simple use of free air, and to obtain very satisfactory results. One method that will be thought of in this connection consists in the filling of one of the compartments, having a surface of about 60 metres, by one uninterrupted operation, allowing the water and grout that will be produced, or any slime that may be produced, and left on the ground, to escape through a special orifice placed at the top of the chamber.

To obtain this result, a large shaft will have to be used, made of steel sheets, and having a sufficient diameter to allow the concrete to pass through it without too much impediment (0·75 metres appear from trials hitherto made to be a diameter that will answer this purpose).

This tube or shaft will have to be filled in with concrete up to the top, and closed at the foot by a "self-closing valve." This valve would have to be opened, so as to permit of the immediate passage of enough concrete to fill one of the compartments.

The introduction of the concrete will occupy from fifteen to twenty minutes, so that when the compartment is filled the funnel should still retain a sufficient quantity of it to form a head and

thus to prevent the water from entering the shaft during the operation. In operating in this manner, and in the case of each of the compartments of the lower part of the caisson, it will beyond doubt be found that the foundation leaves nothing to be desired in respect of strength, since the same operation will be carried out for each separate part. In fact, the whole of the work will consist in repeating partial operations such as these, for which, therefore, suitable machinery will have to be provided, and it may be considered certain that the normal pressure exercised by the concrete remaining in the shafts will be sufficient for the removal of the slime and grout. The test of such practical data as are available in this kind of work justifies the choice of this mode of operation. The only objection that occurs to the mind is, that it is unlikely for 120 cubic metres of concrete to be got ready in the space of from fifteen to twenty minutes. It does not appear impossible, however, to obtain such a supply, nor even difficult, seeing the enormous quantity of concrete that will be required, and the very powerful machinery that must necessarily be employed. Each pier, when immersed and placed on the ground, will have, for a depth of 55 metres below the low-water level, the following data :—

| | |
|---|---|
| Displacement of water (at low water) | 70·513m³ |
| ,, ,, (at high ,, ) | 75·970m³ |
| Difference of tide | 5·460m³ |
| Volume of the pier | 86·000m³ |
| Volume of pockets | 28·800m³ |
| Volume of masonry | 57·200T |
| Weight of masonry | 1·160T |
| ,, caissons | 148·870 |
| Load sustained by the ground | 150·030 |
| Surface of piers at the base | 1·604m³ |
| Load expressed in kilogrammes per square centimetre | 9·3k |
| Weight of metal columns | 2·010T |
| ,, flooring | 7·164T |
| Total load supported by the ground | 157·850 |
| Total load expressed in kilogrammes per square centimetre | 9·8k |

UPPER LEVELLING.—Whenever a pier is fitted in position, it becomes necessary to raise the masonry from the lower water-level up to the base of the metal part, that is, a distance of 20 metres, and up to a height of 15 metres above the highest water-

level, so as to protect the base of the metal columns as far as possible from the action of the breakers. This work, which is not inconsiderable, since it represents 12,000 cubic metres of masonry, will, during the first half of the operation, be sheltered by the upper dome, while the last half of the work will have to be carried on after the dome is removed. The masonry of the upper portion should be provided with walls of hewn granite stones similar to those composing the upper courses. The body should be done by ordinary "filling in" work. Ladders, and even flights of steps, will be provided to facilitate the access of the workmen, or their escape in case of accident. These ladders and steps will also enable the works to be inspected after they are completed.

Erosion at the Base.—If any fear should be entertained as to the liability of the ground at the foot of the piers to become eroded by the currents of the sea, and thus to become less strong and reliable, it will be necessary to protect them by means of sacks filled with concrete, and so piled up, one above the other, as to form a sort of slope round each pier. Such a result could only be obtained by lowering the sacks of concrete with the aid of winches, as they could not be thrown down. A good result may also be attained by forming stone packings around the base of the piers, composed of bulky pieces of rock discharged through special doors or gates (as isolated stones would not descend vertically), the probabilities being that no deviation will take place when they are discharged in one bulk through a door. The compression of ground resulting from such rock packing round the piers would even add to its resistance, if that be desirable.

Special Considerations.—No construction on a large scale has been attempted up to the present time, unless by means of stones sunk to the bottom, which get displaced or broken above the sea. The sea, in fact, often destroys even piers constructed of rocks, so that the safety of vessels in ports is rather jeopardised. It must be recognised, however, that while formerly there was no precedent to assist those employed in the solution of these questions, the experience now acquired has given mankind a great many useful hints by which we ought to profit, and which we must not leave out of sight even in circumstances that compel a totally new step to be taken in the same *direction*.

Taking for granted that the works will be sufficiently protected against the action of the tops of the breakers, and that it will even be possible to shelter them against the less powerful action of the swell, the undulations of which cannot cover more than 100 metres distance from the top of one wave to that of another, or measure more than 2·50 metres from top to bottom, it may be inferred that, in the case of a pier 57 metres long, such a pier will not be thrown out of the perpendicular by any rocking motion to which it may be subjected, and which will only represent a fraction of that sometimes experienced by ships situated near the pier. Piers sunk deep into the water, and forming a considerable bulk, will only undergo part of the effects consequent upon the surface being thrown out of the level, and will present, as already mentioned (even while afloat), the appearance of small islands in regard to the ships that may approach them, while the vessels carrying materials will in most cases follow the undulations of the surface of the sea. The work here contemplated has a certain analogy to the erection of a number of isolated lighthouses upon rocks, which have always caused a considerable expenditure of labour and capital. These works, difficult as they were, did great honour to the able and skilled engineers who devoted themselves to successfully carrying them out, but it is plain that an immense amount of trouble and labour would have been saved had these structures been built upon a metal caisson placed upon the bottom of the sea, in the season when that was practicable. The lighthouse in the estuary of the Oder may be mentioned as an instance illustrating this statement, resting, as it does, upon a metal caisson.

### § 3.—Materials and Machinery required for the Completion of the Works.

The usefulness of a special port for the construction of the caisson, the fitting of the girders, and the sailing and floating plant has been sufficiently dealt with above. Such ports, as before stated, would have to be situated as nearly as possible to the point at which the works are begun upon either coast.

Each of these ports would have to answer the immediate and

special requirements of the work, and have docks or basins enabling four caissons to be formed at the same time, and two more caissons loaded. Each would also contain buildings for storing up the iron and the cement, and the workshops for the manufacture of the metal fittings. In fact, the plant required would amount to an extensive works, that would be called on to supply all that is necessary for the construction of the bridge.

The port will also have to be provided with suitable shunting arrangements, as well as with all that would be necessary to keep the floating plant in good repair. The latter would have to be rather considerable to assist in the erection of the masonry in the offing.

Nothing less than the number of vessels enumerated in the following list will be sufficient:—

Five steamboats of 250 H.P., carrying ballast and various compressed air engines, with the proper fitting.

Ten steamboats of 300 H.P. and 10,000 tons capacity for conveying the working material to the spot. Each one of these vessels should be divided so as to be able to hold convenient proportions of the different descriptions of materials that will have to be employed, and should also be fitted with the necessary machinery for loading and unloading, for the manufacture of mortar and the production of the electric light.

Twenty-five anchoring barges for mooring, each provided with a machine and a winch for mooring and lifting the anchors.

Five tugs or lighters, for keeping the various materials within reach of the works in the offing.

Two barges with masts, yards, &c., of from fifty to sixty tons each, for putting up and taking down the domes.

Thirty unsinkable barges for the port traffic, and for the conveyance of accessories.

The quays will be arranged in such a manner as to receive the goods as they come from the interior of the country from the railway station direct. The quays will be provided with cranes of various degrees of power, corresponding to the weight of the pieces they have to lift.

## IV.—CUBING, ESTIMATES, AND TIME REQUIRED FOR COMPLETION OF WORKS.

The following table shows in a condensed form the relative importance, and the number, of the piers to be constructed, such construction requiring about four million cubic metres of masonry and about seventy-six thousand tons of metal.

*Statement showing the Work Necessary in the Construction of the Piers.*

| Piers under Low Water. | Masonry. | | | Caissons. | |
|---|---|---|---|---|---|
| | Breadth of Piers. | Cubic Metres per Pier. | Total in Cubic Metres. | Weight of Caisson. | Total Weight. |
| Metres. | Metres. | | | Tons. | Tons. |
| 5 | 14 | 17,300 | 242,200 | 311,000 | 4,354,000 |
| 10 | 6 | 20,500 | 123,000 | 386,300 | 2,317,800 |
| 15 | 8 | 24,500 | 196,000 | 466,800 | 3,734,400 |
| 20 | 18 | 28,600 | 504,000 | 561,600 | 10,108,800 |
| 25 | 30 | 31,900 | 957,000 | 618,600 | 18,558,000 |
| 30 | 16 | 37,600 | 601,600 | 697,000 | 11,152,000 |
| 35 | 2 | 40,500 | 81,000 | 790,200 | 1,580,400 |
| 40 | 6 | 43,400 | 260,400 | 873,800 | 5,242,800 |
| 45 | 4 | 48,000 | 192,000 | 966,400 | 3,865,600 |
| 50 | 4 | 52,600 | 210,400 | 1,058,200 | 4,232,800 |
| 55 | 10 | 57,200 | 572,000 | 1,163,200 | 11,163,200 |
| Totals. | 118 | | 3,939,600 | | 76,309,800 |

If it be desired to complete the whole of the works within a period of ten years, which does not seem at all impossible, about two years would have to be devoted to preparatory works for establishing working yards and buildings, so that the whole time, with this preparatory period included, would extend over twelve years. In such a case the foundation-work would have to be completed one year before the superstructure is begun, but it might be commenced even a little before the first year has quite elapsed. Thus ten years may be considered as the limit necessary for the foundation-works and the superstructure.

The labour would have to be divided between two working yards situated on either coast, so that each yard would have to turn out two million cubic metres of masonry, concrete, and caissons,

to the amount of 40,000 tons each in a year, with the amount of 200,000 cubic metres of masonry, and 4000 tons of iron caissons. The iron would be supplied from existing works, and no difficulty would be encountered in this respect, but, in addition to the 4000 tons annually required for the caissons, there would have to be added the metal necessary for the superstructure. The plant required to meet this demand does, however, exist, and this is the main point.

As regards the masonry, there are some difficulties that would have to be contended with, not on account of the quantity of 200,000 cubic metres that must be turned out every year, but owing to drawbacks inherent to any work to be performed in the sea, as well as to the inconvenience attending the conveyance of men to the spot, and the loading and unloading of materials.

In the maritime works performed in the port of Antwerp 600 cubic metres of masonry or of concrete have been turned out every day, and in the construction of docks at Misiessy 200 cubic metres of masonry for each caisson were easily supplied. At Boulogne and at Calais, the condition of the sea enables work to be carried on by dredging machines from 200 to 250 days per year, which goes to show that if in the Channel bridge a better adapted and stronger material be used, the works can be carried on from 40 to 50 days longer, *i.e.*, from 250 to 300 days a year, or, on an average, for 275 days per annum. Deducting the holidays, however, the work will not be continued for more than 250 days, so that it will be necessary to turn out each day $\frac{200,000}{250} = 800$ cubic metres of masonry.

It does not appear to be possible to put more than 100 cubic metres of masonry per diem into one pier caisson, so that to obtain the total quantity of work required it would be necessary to operate on eight caissons at once, and, besides, perform the preparatory and supplemental operations separately.

In estimating the time that would probably be required to perform each of these operations, one can at once form an idea of the number of columns that will have to be operated upon at the same time.

*Details of Construction of Caissons.*

| Average Column with Base at 30 Metres below the Low-water Level. | Quantities. | Time. |
|---|---|---|
| | | Days. |
| Construction of caissons. . . . . . . | 697,000k | 60 |
| Loading same before moving . . . . . | 2,200m² | 10 |
| Conveying same to place of sinking . . . . | | 2 |
| Masonry to be erected before sinking . . . | 17,500m³ | 175 |
| Clearing the ground (?) under the edge. . . | | 30 |
| Fitting in place and final clearing of ground . . | | 20 |
| Application of concrete . . . . . . . | 2,400m³ | 20 |
| Time lost through bad weather and holidays . | | 160 |
| | | 477 |

The supply of the immense quantity of materials necessary does not appear to offer any very great difficulties. As regards the concrete, and the rough bricks and stones, the chalk quarries situated near Marquise may easily be taken advantage of, and they will probaby suffice to supply all that is required in this respect.

The shipping of such materials may be divided among the ports of Calais, Boulogne, and Ambleteuse proportionately to the facilities which each of those ports offers. The unloading on the spot where the work is carried on will be effected by labourers, with special machinery, and no complications are to be feared in this connection, except such as may arise from the unsatisfactory condition of the sea, which may be guarded against in the manner indicated in the preceding chapter.

The sand required for making the mortar will be supplied by the beach.

Cement is manufactured in considerable quantities all around Boulogne, from whence 50,000 tons per annum can be easily obtained. The granite for the capping of the piers may be derived from the quarries of Chausey, Flamanville, &c., situated on the coast, and placed beforehand in a condition suitable for the purpose.

# PART III.

## SUPERSTRUCTURE.

*Preliminary Project of Messrs. Schneider & Co.*

## IV.—CHOICE OF SYSTEMS OF GIRDERS.

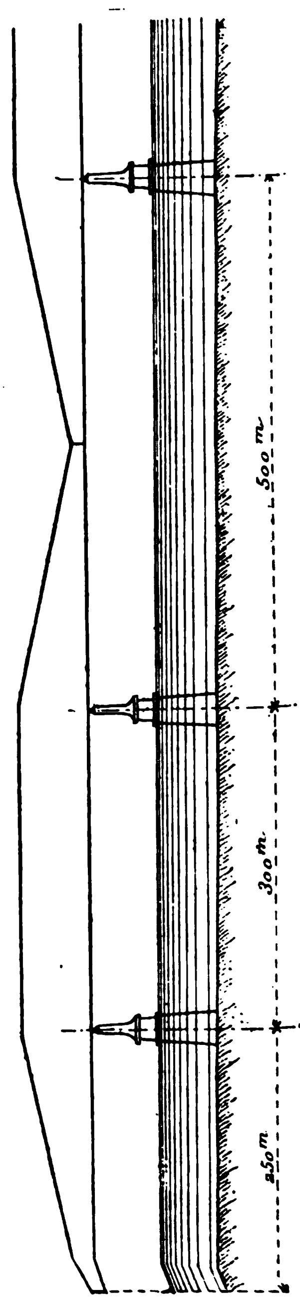
The idea of placing non-continuous girders upon piers erected at regular intervals of 500 metres must be rejected at once. It is true that this system would offer the unquestionable advantage of considerably reducing the number of piers that might cause an obstruction to the navigation; but it would, on the other hand, be attended by the drawback of unduly increasing the weight of the bridge, for it is well known that the weight of a girder with two points of support increases much more rapidly in proportion to the span than is the case with a continuous girder.

It would seem advisable to cover the large spans by cantilevers, but such an arrangement requires that between the points of support of the same girder a sufficient length should be left for ensuring the stability of the work during construction, and to make up for the varying distribution of the additional load, as well as to meet the emergency of excessive gusts of wind.

It will be understood that, from the standpoint of economy, it would be desirable to reduce this length as much as possible—100 metres, for instance, would be a satisfactory length; but then it may be objected that, in many cases, these lengths of 100 metres would interfere with navigation, especially with that of sailing-vessels. It would, therefore, be necessary, in order to avoid multiplying such obstacles, to increase the distance between the piers. This distance has consequently been fixed at 300 metres at the deepest part of the sea, where the cantilever spans would therefore attain 500 metres. It has been stated before that, in addition to the alternate spans of 300 and of 500 metres, there would also be spans of 200 and 350 metres, and another set of spans of 100 and 250 metres respectively, to be placed at the points corresponding to the elevated portions of the ground, and in the vicinity of the coasts.

In considering the spans of 300 and 500 metres, the first idea that occurs *is to form the spans of* girders extending over the

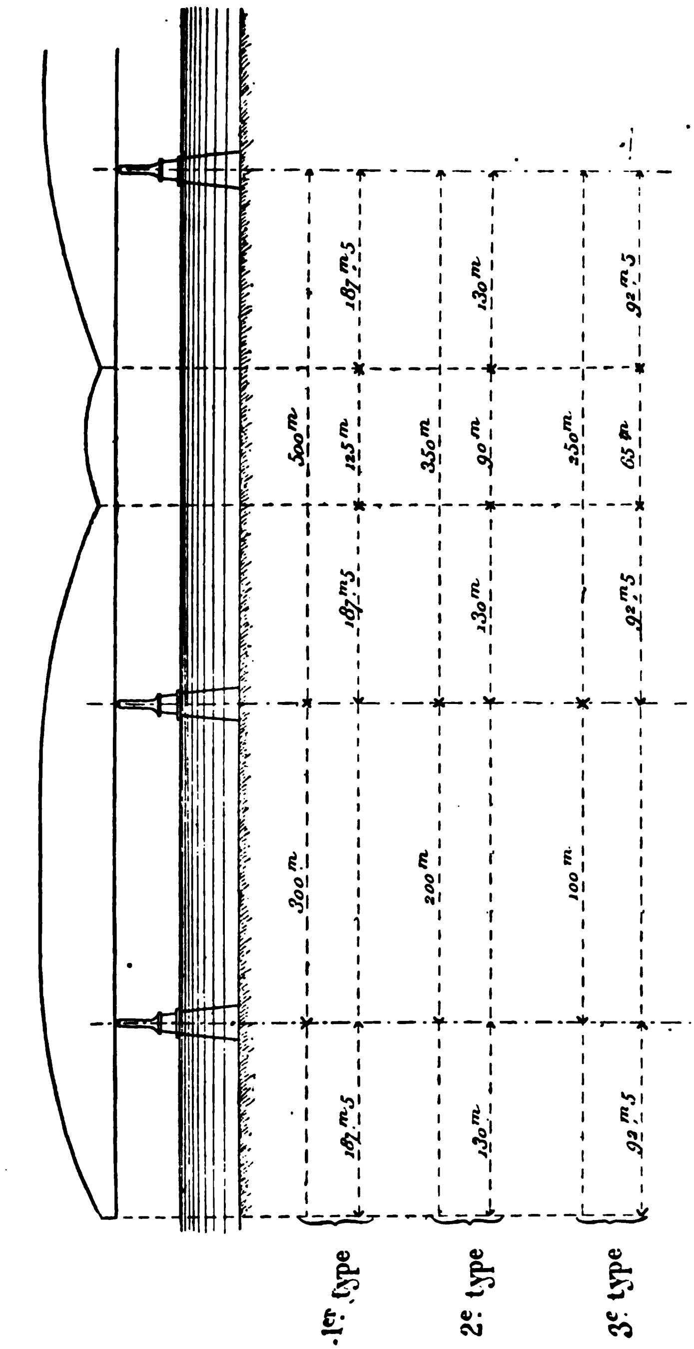
whole length of 300 metres, and extending on either side in the form of cantilevers of 250 metres, so that the junction of two cantilevers should constitute a span of 500 metres in all. The accompanying sketch shows this arrangement.




It is a well-known fact that in the Forth Bridge the two large spans are not completely covered by the cantilevers, the latter being connected by an ordinary central girder.

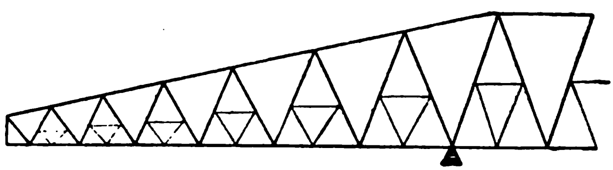
It therefore becomes necessary to ascertain whether the addition of such a central girder would result in diminishing the weight. The nature of this paper does not enable us here to reproduce the calculations to which this inquiry has conducted us, but it may be stated that these calculations have shown that the addition of a central girder is advisable, and that, supposing the distance between the points of support to be 500 metres, the space comprised between one - third and one-fourth of the distance between the points of support is the best indication of the length to be given to the same, for by this means a saving of about 17 per cent. is realised on each of the cantilevers. The sketch on p. 69 shows the arrangements adopted for the three types of spans.

It now remains to determine what arrangement is to be adopted with *regard to* the main girders of the

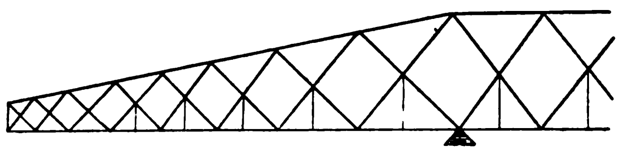

500m
300m
187m5
125m
187m5
187m5
350m
200m
130m
90m
130m
130m
250m
100m
92m5
65m
92m5
92m5
1er type
2e type
3e type

bridge. The best girder will be the one that will necessitate the employment of least weight while offering sufficient resistance to vertical loads and presenting the least surface to the wind.

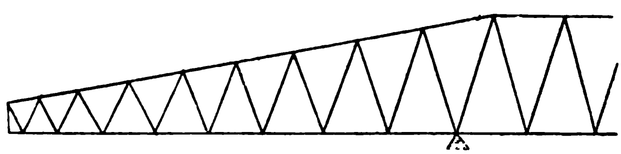
Many types of girders of the same height, and presenting about the same intervals between the lower apices, have been examined, it being desirable to avoid taking into consideration the weight of the beams and of the sleepers under the rails.



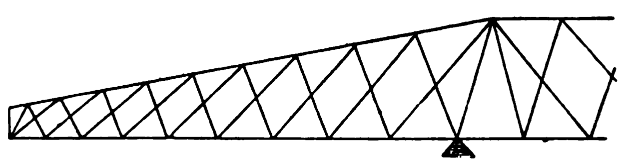
Warren Laced Girder.



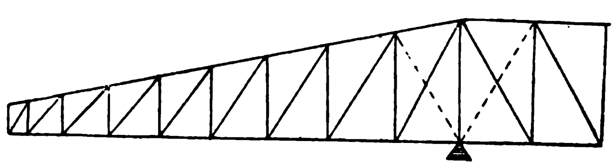
Warren Compound Girder.



Warren Simple Girder.



Post Girder.



Pratt Girder.

The following table shows the weight of the different girders as compared with the weight of the Warren compound girder:—

| | Warren's Laced. | Warren's Compound. | Warren's Simple. | Post. | Pratt. |
|---|---|---|---|---|---|
| Weight to resist vertical strain | 1·000 | 0,957 | 1,063 | 0,956 | 1,190 |
| „ „ wind . . | 1·000 | 1,157 | 1,241 | 1,350 | 1,080 |
| Proportional average . | 1·000 | 1,047 | 1,143 | 1,133 | 1,141 |

This proportional average has been calculated on the assumption that the weight necessary to resist the wind represented $\frac{9}{11}$ of the weight sufficient to withstand vertical strain. The question has been carefully inquired into, and the present report is the result.

It will be seen that the Warren compound girder offers most advantages, and therefore this type of girder has been selected. The same girder has also been adopted for the independent spans connecting the consecutive cantilevers.

## V.—ARRANGEMENT OF METALLIC SUPERSTRUCTURE.*

### § 1. Spans of 300 and 500 Metres.

It is proposed to provide the bridge with two lines of way situated 1·50 metres apart. The upper level of the rails will be 72 metres above the low-water level, the lowermost portion of the bridge being 61 metres above the low-water level throughout the extent of the spans of 300 metres, while in the centre of the spans of 500 metres, that portion is 66·50 metres above the low-water level.

Central Span and Cantilevers.—The superstructure of the bridge is formed of two girders, resting upon two piers 300 metres apart, and lengthened on either side to the extent of 187 metres, the arms of the cantilevers being thus 500 metres in length. These girders are 11 metres deep at the ends of the cantilevers,

* The calculations relating to the superstructure for the contemplated Channel bridge were undertaken by M. J. B. Pradel, managing engineer of the Chantier de Creusot at Chalon-sur-Saone.

and 65 metres high almost throughout the span of 300 metres. Each girder consists of a top and bottom member connected by latticed girders forming isosceles triangles. The lower members of the two girders have a distance of 25 metres between their axes in the central span of 300 metres, and an interval of 10 metres at the ends. They are horizontal in the central span, but are raised to a height of 5 metres at the ends of the cantilevers. The upper members are connected in the largest portion of the central span, but diverge at a certain point, so as to be 10 metres apart at the ends, and this is also the case with the lower members; in the cantilevers they assume the shape of polygons inscribed in a circle of 650 metres radius.

All the principal members of each girder, as well as the latticed girders, are formed of plate and section iron divided into four segments. The inclined members are of simple sections.

The lower members are square in section. They are 2 metres across in the central span, but decrease in height towards the ends of the cantilevers down to 1 metre. The tip members have the same width as the lower ones, but as the segments of which they are composed are longer, their section varies between 3 metres and 1·50, and their size is variable, according to the open length. The distance between the principal lower apices of each girder varies between 50 metres and 6·50, so as to make up as far as possible for the difference of direction of the inclined members.

The lower members are connected by cross-shaped bracings, the bars of which are of hollow circular section. Cross bracings between struts or compression members of the two main girders give additional strength to those girders and increase their resistance to the wind.

CENTRAL GIRDER.—The independent span of 150 metres rests upon the ends of the cantilevers. The depth is 11 metres on the ends and 20 metres in the centre, the sides being 10 metres apart. Each girder consists of four members, the lower members being horizontal and the upper assuming the shape of a polygon inscribed in a circle, both being connected by web, forming isosceles triangles.

The two members are formed of sheet and section iron divided

into four segments of identical shape. Their common height varies from 1 metre (at the ends) to 1·50 (in the centre of the span). The web is of the same type. The secondary bars are of simple section.

The lower and upper members of the main girders are connected by cross-shaped bracings, the bars of which are of tubular section. Here, also, there are cross-bracings corresponding to the compression members of the two girders.

The Flooring Proper.—The two lines of rails are supported by four rows of longitudinal beams disposed parallel with the rails. These beams are latticed. Their height and span are unequal, and their dimensions vary according to the stress they are to resist.

The rails are to be embedded in a groove to avoid accidents. The plates are formed of ribbed iron 8 millimetres thick, weighing 50 kilogrammes per square metre. They rest upon ⊥-shaped irons.

The footways are provided with balustrades fixed upon the overhanging ledges attached to the external beams. The horizontal beams under the rails are carried by cross girders, each of which connects two of the lower apices of the main girders. All these pieces assume the shape of a Warren girder with three bays. Their depth is variable, and the bars of which they are composed are of hollow tubular section.

Piers.—The metal portion of the piers comprises two columns of 34·900 metres high. Each column is formed of two cylindrical cores having a common axis, and a diameter of 4·600 and 6·400 metres, respectively; twelve such cores arranged precisely vertically serve to connect the others, and by their prolongation form external and internal stiffeners.

The interior stiffeners have a free space of 3 metres, which is invariable throughout the height of the column. The outer stiffeners give the body of the pier an apparent diameter of 8 metres, which gradually increases to 12 metres towards the base.

The inner cylindrical core is provided with a prolongation of 14 metres, forming an anchoring tube of 4 metres in diameter; but as it would be insufficient in case of a longitudinal action of the wind, and also to provide for expansion, twelve anchor bolts, holding down bolts, have been added, forming the bed of each column.

These bolts have a diameter of ·250 metres, and their action extends over a height of 14 metres of masonry.

The two columns of the same pier are connected by bracings which enable them generally to resist the transverse action of the wind.

The piers terminate at the top in ledges carrying the balustrade.

A circular plate 6·200 metres in diameter, and 1·400 metres in height, covers each column, and is formed of sheet iron, serving to receive the supporting apparatus with a fixed or expanding foot.

The expansion gear comprises six rails, ·600 metres in diameter and 3 metres in length.

The load is transmitted from the floors to the piers through the bedplates, hence it is distributed all over the sheet iron plates and angle irons, braced together so as to prevent overturning under the action of the wind.

The columns of one pier are fixed, while the columns of the next pier have expansion gear. The effect of the expansion or the contraction of the flooring results in a corresponding reduction or augmentation of the play between the ends of the cantilevers and the ends of the central girders. The span rests on one side upon fixed supports, on the other on rolling gear.

## § 2. The Spans of 200 and 350 Metres.

The upper level of the rails is 72 metres above low-water level. The lower portion of the bridge is supposed to be at 62·680 metres above the low-water level throughout the whole extent of the spans of 200 metres, while in the centre of the spans of 350 metres the height above the low-water level is 66·497 metres.

The whole of the spans of 200 metres and 350 metres being similar to the spans of 300 and 500 metres, it will suffice, after what has been said in the preceding paragraph, to refer to the plans in order to comprehend the arrangement adopted with regard to this type of span.

### § 3. The Spans of 100 Metres and 250 Metres.

The upper level of the rails is always 72 metres above low-water level.

The lower portion of the bridge is quoted as being at 63·780 metres above low-water level throughout the spans of 100 metres, while in the centre of the spans of 250 metres the height above the low-water level is 66·497.

To comprehend the arrangement adopted in the case of this latter type of span, it is sufficient to refer to the plans accompanying the paper.*

## VI.—CONSTRUCTION, TRANSPORT, AND ERECTION OF THE METAL SPANS.

### § 1. Description.

The important work of putting down a complete fitting-up plant will have to be carried out upon the coast in the vicinity of the abutment of the bridge. The small port of Ambleteuse, sufficiently sheltered from the winds of the offing and the effects of breakers, seems to be best adapted for this plant, which, as already described, consists of two quays provided with suitably arranged jetties. These are intended to sustain the weight of the whole metal framework, and therefore constitute an essential part of the plant. The quays are to connect these jetties. They are supplemented by a channel of sufficient width and depth to allow each loaded span to wait for a favourable moment to be placed on the piers by means of tugs.

Upon the quays scaffolding will be erected, supplied with powerful and improved machinery, such as cranes, steam winches, and hydraulic lifting machines.

The various parts of the bridge will reach the working-yard in as complete a condition as possible. A greater or less number of works may be applied to to manufacture these different parts, in order to avoid the necessity of rapidly calling into existence a

* The paper was illustrated by a large number of diagrams, of which only the more important have been reproduced. The full series may, however, be examined at the Institute.—Ed.

regular industrial town on a desert part of the coast, and thus obviate any disorder that may result from so doing, either while the works are proceeding or after their abrupt completion. The fitting together of all the pieces can be mainly done in the work-yards, as regards the central spans and the cantilever arms. Once fitted up, each span will have to be freed from all the supports except those upon which it is supposed finally to rest. They must then be sufficiently shifted along the jetties to enable them to be placed on the barges provided for carrying them to their ultimate position.

The power required for hoisting the bridge is not such as to be above the capacity of hydraulic cranes. Let us, in fact, consider the case in which the difficulty appears to be most serious, namely, that of the central span of 300 metres, with 50 metres in overhanging portions on either side, weighing 9580 tons. Supposing the co-efficient of friction to be ·10, it will be seen that the effort necessary will only amount to 958 tons. Particular attention should be paid to the arrangement of the slides.

As the pontoons must be adapted to remain upon the supports for a certain time, means must be provided for turning it round. The supporting surface is to be formed by the base of a cone carrying the turning socket. Thus, in the case of the heaviest span, a surface of 15 square metres will be obtained for 4790 tons, which amounts to 32 kilogrammes per square centimetre.

The slides will have to be strongly fixed to the masonry. To avoid their breaking under the strain they will have to undergo, they must be able to support about 500 tons at the transverse section, their width being 2·50 metres. They must evidently be about 20 millimetres thick. They will rest upon wooden cross-bars, lest, in consequence of some difficulty in the execution of the work, an excessive pressure per unit of surface should result in at any given point, the consequence of which would be a fracture of the metal.

The loading will be effected at high water. The barges will be brought up to the pontoons before the tide, and will raise it when the tide sets in. The whole will then be disengaged by transverse traction by means of winches.

There may be three barges in the case of the heaviest span.

These craft must therefore have a nominal capacity of about 3200 tons, and a displacement of about 5500 tons when fully loaded, including the weight of the scaffoldings provided for supporting the span.

Barges 22 metres wide, 70 metres long, and drawing 6·50 metres, will answer the purpose.

They will also fully insure the stability of the whole. The pontoons may then sustain a considerable transverse pressure of wind without rendering the resulting inclination dangerous.

The various barges will be connected together by means of steel cables, stretched crosswise, as is sometimes done in the case of bridges over rivers for the passage of artillery in times of war.

The barges should be provided with compartments that can be filled with water by means of sluice valves, so as to second the action of the tide during the discharging operations. It will thus become unnecessary to follow all the movements of the sea, while nothing should prevent fair weather from being taken advantage of.

The whole of the parts of the pontoon and the barges will be tugged by a large steamer, by means of crowfoot lashings, which is preferable to using several tugs, which might not act with the desired uniformity.

It will be understood that whenever the distance from fixed points, either on the shore or at the piers, makes it possible, it will be best to use direct traction and sufficiently powerful steam winches. It will be necessary, at the point where the girders are to be laid down upon the piers, to provide sufficiently powerful buffers to intercept the shocks due to the movement of the sea.

When the portion of the bridge has reached the position it is to occupy, and is brought to rest at four points on the piers of masonry, the raising of it by means of hydraulic presses, arranged inside the rings which form the base of the metallic piers, will be proceeded with.

The portions of the bridge will then be raised to the required height to enable the sections of the piers being replaced in position. The presses will afterwards be withdrawn, and the operation may continue in the same way until the span assumes its ultimate position.

By adding to the weight to be thus raised the strain produced by the wind, it will be seen that each of the presses placed within

the metal piers should be endowed with an effective power of 2900 tons.

It has been stated before that the large spans were not to be quite completed on the shore. As regards the cantilever arms, they will be placed in position by a process of free erection step by step similar to that used by the Creusot Company in 1865 for the bridge across the river El Cinco (Spain). As to the central girders, they may be completed in the yard. They can then, by means of barges, be brought under the two cantilever ends which they are to connect, and there raised to their ultimate position by means of sufficiently powerful hoisting apparatus.

## § 2. Calculation of the Machinery employed in Fitting Up.

Buffers.—The *vis viva* to be deadened in case the buffers should be acted on by movements of the sea occurring at the time of disembarking on to the piers, may be regarded as practically equal to half the mass of the pontoon, multiplied by half the square of the speed acquired by the end imparting the shock, viz., $\frac{PV^2}{2g}$. In taking this figure for a starting-point one may be certain that the real amount is exceeded, for, supposing the bridge rotates about its centre, the sum of the momenta would still be below that figure.

Suppose, now, that the shock is to be relieved by twelve buffers of the railway type, arranged within each of the piers, the strongest of these buffers are capable of moving a distance of ·10 metres and of carrying a load of eight tons. The available labour, therefore, can be set down as practically equal to $\frac{8 \times 12 \times \cdot 1}{2}$, which quantity must be equal to half the momentum, viz., to $\frac{2400}{19{\cdot}62}$v2.

Therefore v equals ·198 metres per second.

Now, a swell sufficiently long to affect the barges, corresponds, as is well known, to a time of oscillation of about 3″. Thus the average velocity, as worked out above, would correspond, in a similar oscillation, to a rise of the sea of ·594 metres per second.

This, however, is an amount of lifting which may be avoided in *effecting the discharge*, especially in the summer.

A more precise calculation can be made by taking the force of inertia into account, but it seems unnecessary to dwell further on this point. It will be easily seen that there need be no difficulty in deadening the impact due to the velocity imparted by the waves.

BARGES.—The case more particularly considered here is that of the heaviest span, it being the one attended by most difficulties.

The first condition to be fulfilled as regards the barges is to make it impossible for them to capsize, and to insure their stability. This object can be attained by placing the centre of gravity of the whole below the longitudinal meta-centrum. It can be taken for granted that the centre of gravity of the empty hulls of the barges will be 1 metre above the floating-line of the load, since they will be surmounted by a superstructure rising up to 20 metres above the floating-line, and since they will, when fully charged, rise to 4·15 metres above the water, their draught being 6·50 metres.

This being so, the bridge, weighing 3·200 tons per barge, and having its centre of gravity 49 metres above the water, the general centre of gravity according to the calculation of weight will be—

$$\frac{3 \cdot 200 \times 49^{m} \times 2 \cdot 300 + 1}{5 \cdot 500} = 29 \text{ metres,}$$

the draught of the barges being 6·50 metres; the minimum height of the longitudinal meta-centrum, above the centre of the keel, will be about 32 metres.

Now, supposing that barges are used measuring 22 metres in width, and 70 in length, the height of the meta-centrum, with a displacement of 5·500 tons, will be about 40 metres. Thus stability will be amply provided for, and the distance of the centre of gravity from the meta-centrum will be 8 metres.

This distance is sufficient, as will be shown further on, to insure stability under a wind coming transversely upon the bridge with a considerable pressure.

The surface the bridge will offer to the wind in that direction will be 87·50 square metres, and the centre of pressure is situated 21·35 metres above the girders, that is, 46·5 metres above the surface of the water.

If $p$ be the pressure of the wind per square metre, the momentum of the wind about the line of flotation will be—

$$8{\cdot}750 \times 46{\cdot}85 \times p.$$

If $\theta$ is the incline assumed by the barges, then P (R—A) sin. $\theta = 8{\cdot}750 \times 46{\cdot}85 \times p$. P being the total displacement, and R—A being the distance of the centre of gravity from the metacentrum, this distance we have assumed to amount to 8 metres, and P is $= 16{,}500{,}000$.

Now, it is desirable that the immersed end should not go down deeper than $2^m$, 50 :—sin. A must not exceed $\frac{2{\cdot}5}{35}$.

It follows that the pressure per unit of surface which the whole structure will be able to sustain will be equal to—

$$p = \frac{16{,}500{,}000 \times 8 \times 2{\cdot}5}{8{\cdot}750 \times 46{\cdot}85 \times 35} = 23 \text{ kilogrammes.}$$

Thus even a violent storm could not possibly cause capsizing.

But, granting that this point has been sufficiently illustrated, it may be questioned whether the portions of the bridge will not run the risk of being deformed under the strains they will be subjected to by the barges themselves during transport, especially if the operation is not carried out in perfectly fair weather.

It is obvious that if there is but little sea running, so that the waves are insufficient to influence the barges themselves, the whole operation will proceed as if they floated upon a perfectly smooth sea, so that no anomalous strains would ensue.

As to traction, or those strains that will result from gyration, it will be readily seen that they will be of no great importance, if all the operations are performed slowly—*e.g.*, the towing power necessary to tug the pontoon at a speed of eight knots will not exceed 150 tons, even if a very sharp wind happens to add to the resistance proper; such wind exercising a pressure of 10 kilogrammes per square metre, the towing power need not exceed 160 tons. Now, the pontoon has been calculated to resist more considerable transverse strains than that.

While one may reasonably depend on having fairly good weather in the Channel during the summer, it may happen, nevertheless, that the barges, upon leaving the port, may encounter a

considerable swell, at least in length, which, although not very noticeable, may exercise on a girder more powerful strains than those provided for in the preceding calculations.

Thus, it may happen that the swell exercises on one of the barges a lifting strain that will be transmitted to the pontoon. This strain will be equal to the floating surface of the barge, multiplied by the distance between the ordinary floating line and the medium floating line, determined by the section of the wave. Now as the floating surface extends over about 1000 square metres, it will be seen that a wave that would cause the floating line to rise 50 centimetres, would cause a thrust of 500 tons. Such a wave, however, would have a lifting power considerably above 50 centimetres, inasmuch as its section is never a horizontal line. One may set it down at 75 centimetres in the least favourable case.

This strain of 500 tons, however, would not in itself prove dangerous, considering the sections of the girders and the use of lashings. It will thus be seen that, from this point of view also, the transport would be by no means impossible.

We have hitherto considered only those stresses from which the girders are naturally protected, such strains acting in the same way as those which the girder is originally destined to withstand; but the girders will be exposed, besides, to another kind of strain —that of torsion—which they will sustain whenever the barges that carry them tend to take up positions at different angles to the perpendicular, in consequence of the varying inclinations of the waves.

These are the stresses that require special attention. Let us then consider the part of a girder comprised between the two pontoons. They will assume a certain relative position, corresponding to an angle of torsion of the bridge $\theta$, and will assume the inclines $\theta'$ and $\theta''$ respectively, in relation to the liquid surface upon which they float. If we call $\alpha$ the angle formed by the two floating surfaces, we obtain

$$\alpha_1 = \theta_1 + \theta' - \theta''.$$

On the other hand, the moment of stability of the first barge is P (R – A) $\theta'$, that of the second P (R – A), and the couple which counterbalances the twisting strain is

$$P\,(R-A)\,(\theta'-\theta''),\ or\ P\,(R-A)\,(\alpha-\theta_1).$$

It is equal to a moment of torsion of

$$\frac{\theta_1}{l} I_p G = P(R-A)(\alpha_1-\theta_1).$$

But, on the other hand, if $\sigma$ be the effect of the strain upon the part supporting the heaviest load, this effect is proportionate to $\frac{\theta_1}{l}$, *i.e.*, to

$$\frac{P(R-A)_1}{I_p G + lP(R-A)} = \frac{\alpha_1}{\frac{I_p G}{P(R-A)} + l}$$

From this expression we cannot yet obtain the value of $\sigma$; but we may infer from it that it is desirable, within certain limits, to multiply the number of barges.

Supposing, in effect, that they are uniformly divided, the displacement P of each will be proportionate to the distance between them, as $l$ and $\frac{P}{l} = c$.

Let $h$ be the distance of the centre of gravity from the part farthest off; we obtain

$$\sigma = Gh\frac{\alpha_1}{\frac{I_p G}{P(R-A)} + l} = Gh\frac{\alpha_1}{\frac{I_p G}{lc(R-A)} + l}$$

The value of $l$, corresponding to the maximum of $\sigma$ is

$$l = \sqrt{\frac{I_p G}{c(R-A)}}$$

By this formula a far greater length than that of the girder will be found.

As $l$ diminishes, $\sigma$ decreases too; thus it will be seen that it is desirable to increase as far as practicable the number of barges.

The necessity for the girder to rest upon parts capable of a local resistance, leads to the adoption of the number *three* for every 9·580 tons. Less than this cannot be taken in the case of the other spans.

Given a distance between the barges $l$, and the angle $\alpha_1$, of the floating surfaces of two consecutive barges, the corresponding value may be calculated from $\sigma$. But an easier method is to

find out at what angle $a_1$, $\sigma$ equals a torsion of 6 kilogrammes per square millimetre.

It will then be found that $a$ should be equal to something more than 200°; we are therefore justified in concluding that the torsion produced, even by very powerful waves, will only cause perfectly insignificant strains.

All the preceding calculations are naturally only approximate; they nevertheless permit the inference that the transport of the spans is quite possible.

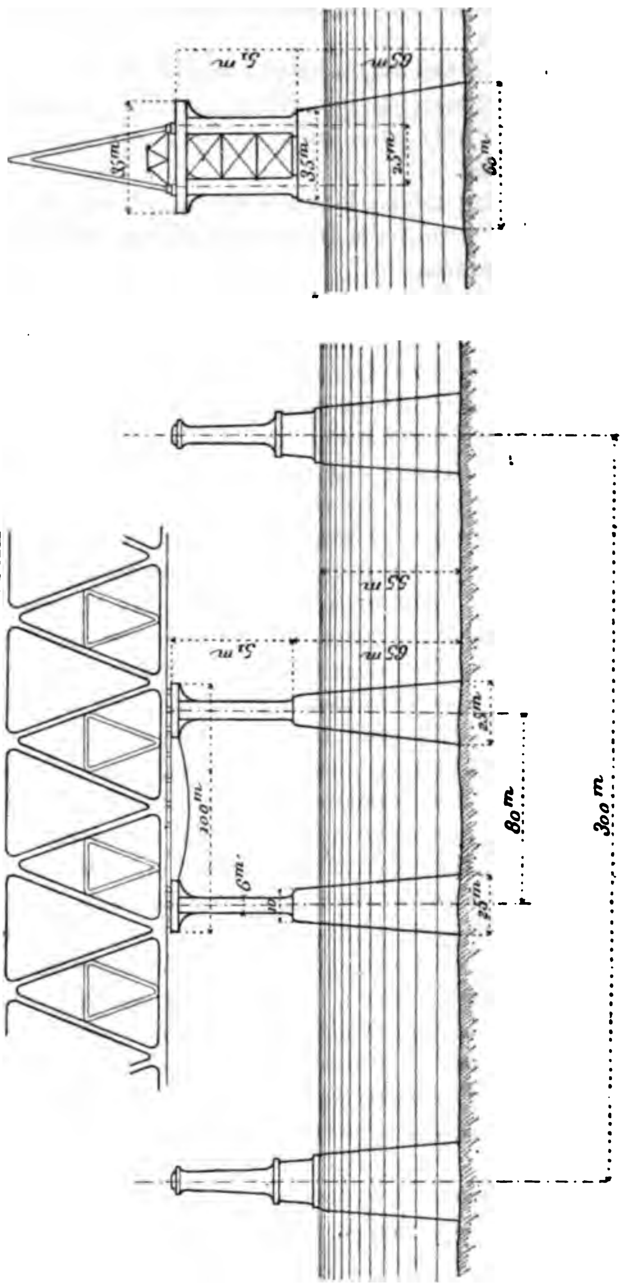
## § 3. The Erection of the Cantilever Arms.

We here treat of a method of putting into position the central spans and cantilevers, so as to avoid the employment of the hydraulic cranes, as described above.

The necessity of raising the girder by hydraulic presses each time one places a ring of the columns into position necessitates a series of alternative manipulations, requiring a great deal of time and trouble. It is easy enough, on the other hand, to mount the columns separately by small sections by the aid of hoisting gear of less power; but as the carriage of the spans on floating barges is not to be thought of, it being too difficult to thus bring them into a position that will permit them to be raised to the place they are to occupy, the result is that it is necessary to fit up these spans at the required height straight away. The idea might at first sight suggest itself that the piers already constructed should be used as supports. For, by surmounting them each separately by a platform of sufficient size to ensure stability, it would be possible to fit the spans step by step by free erection on either side of each pier. The junction of the two sections of a girder would then have to be made in the centre of the central span; but whatever care is taken in carrying out this operation, it would leave serious doubts as to the continuity of the girders, such as is assumed in the calculations.

It is by far preferable to commence the mounting in the centre of the central span with the aid of auxiliary and removable piers interposed between the piers that are to be left standing permanently.

In the case of the larger spans, two piers might be arranged, as shown in the following sketch.


5m
65m
35m
3.5m
25m
60m
55m
5m
65m
100m
6m
80m
300m

These piers are formed of two columns, each 51 metres high, and 6 metres in external diameter, with cross bracing, and resting upon a caisson, the form of which, in horizontal section, is that of a rectangle terminating in a semicircle, so that it should oppose the least possible resistance to the currents.

At the top the caisson is 35 metres long and 10 metres wide, and at the base 60 metres long and 5 metres wide. Its height is 65 metres for the maximum depths. The two piers here considered are so situated that there is a distance of 80 metres between their axes, and they are connected by a superstructure forming a platform 100 metres long by 35 metres wide.

It is on this platform that the fitting up of the different parts of the bridge will be effected, just as if it was in an ordinary work-yard on land, and here the construction will be continued, by means of free erection, step by step, until, on either side, the permanent pier is reached, which will then have to be completed so as to be able to receive the girders. When once the span finally rests upon the piers, the mounting operation can be continued with the assistance of the auxiliary piers. The superstructure can then be removed as well as the columns, and both can be used together, with the caissons, in fitting the next span into its place.

Each caisson being of dimensions comparable to those of the caissons provided for in the case of the masonry surrounding the columns, it will be possible to set it afloat and ground it, after being provided with the compartments necessary for receiving the sand ballast. Its cubical volume being about 51,000 cubic metres, it will be necessary to fill a little over one-half of it with sand in order to make it ground. With the caisson in position, it may still be found, even after it has been loaded with the columns, the superstructure, and the portions of the bridge then in course of completion, that infiltrations have taken place at its base, which would give a thrust equivalent to 43,500 tons. This being so, a ballast of about 8000 cubic metres of sand will have to be added, in order to insure the stability of the whole under the action of wind at the time that the bridge girders are about to be placed upon the piers intended to support them.

For the fitting up of the intermediate spans, two auxiliary piers seem to be necessary.

As to the smaller spans, where the piers of the bridge are 100 metres apart, one single auxiliary pier will be sufficient, if it be connected with the permanent pier by a platform.

## VII.—ESTIMATES OF WEIGHT.

The following weights have been obtained by adding to those found by calculations 18 per cent., to provide for additional pieces that will be employed in fitting and riveting. Taking all parts together, the limit of stress is assumed to be 12 kilogrammes per sectional square millimetre, the rivet bolts not being subtracted.

This limit, however, may be considered as a very high one, for it has never been reached hitherto in any of the steel structures that have been built; but, nevertheless, after carefully examining the conditions involved in the question, it will be found that the assumption of such a limit is not unjustified.

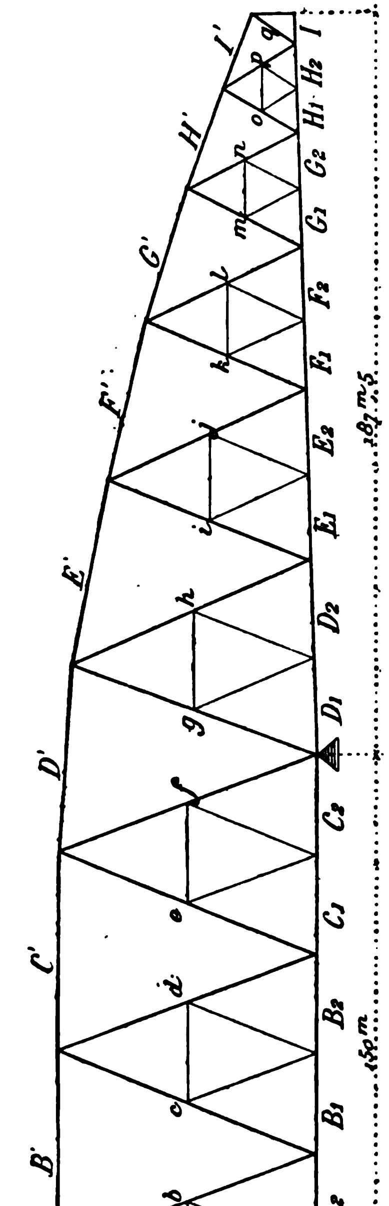
In the present case the permanent load represents $\frac{8}{11}$ of the total load. From the formulas deduced from the experiments of Wöhler, it appears that the limit of stress of 12 kilogrammes offers the same guarantees of safety as a limit of 10·5 kilogrammes in the case where the permanent load and the additional load have equal influences.

In the case of such pieces as the longitudinals under the rails, and the tension members, where the additional load greatly exceeds the permanent load, it may be said that the addition of 18 per cent. is certainly excessive—in fact, that it surpasses any figure suggested by a lengthy experience. Even as regards the other parts of the bridge, this figure may be regarded as exaggerated, owing to the use of sheet iron and section irons that can attain 12 metres in length, which would notably reduce the importance of the fittings. It must be added that in calculating these members, very liberal allowance has been made for any unforeseen excess of weight, since instead of calculating their real length, the distance between their axes has been taken into account.

To simplify calculations, the same co-efficient (12 kilogrammes) has been admitted as applying to all the members of the bridge. In a final project, however, it will be necessary to examine whether it is not more rational to assign to each part a co-efficient of resistance varying with the size and the direction of the stress to which that particular part is subjected.

## § 1. Spans of 300 Metres and 500 Metres.

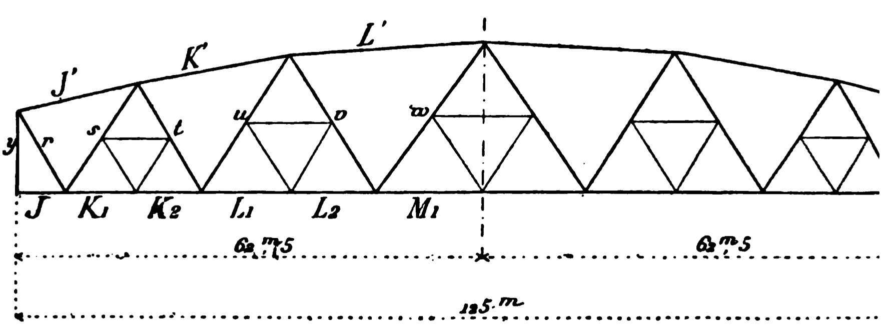
### 1. *Central Span and Cantilever Arms.*



| Central Span. | | | | | | Cantilever Arms. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Lower Members. | | Upper Members. | | Bars. | | Lower Members. | | Upper Members. | | Tension Members. | |
| | Tons. | | Tons. | | Tons. | | Tons. | | Tons. | | Tons. |
| $A_1$ | 76,093 | A' | 45,088 | *a* | 22,839 | $D_1$ | 137,231 | D' | 172,280 | *g* | 125,527 |
| $A_2$ | 78,010 | B' | 96,293 | *b* | 28,658 | $D_2$ | 127,419 | E' | 106,670 | *h* | 108,914 |
| $B_1$ | 92,230 | C' | 121,117 | *c* | 59,267 | $E_1$ | 77,251 | F' | 59,976 | *i* | 64,494 |
| $B_2$ | 98,059 | | | *d* | 74,950 | $E_2$ | 70,487 | G' | 33,340 | *j* | 56,578 |
| $C_1$ | 126,814 | | | *e* | 122,537 | $F_1$ | 40,198 | H' | 16,320 | *k* | 30,756 |
| $C_2$ | 136,820 | | | *f* | 166,146 | $F_2$ | 35,972 | I | 4,528 | *l* | 28,261 |
| | | | | | | $G_1$ | 18,702 | | | *m* | 14,338 |
| | | | | | | $G_2$ | 15,950 | | | *n* | 14,706 |
| | | | | | | $H_1$ | 5,992 | | | *o* | 7,167 |
| | | | | | | $H_2$ | 6,913 | | | *p* | 9,485 |
| | | | | | | I | 3,833 | | | *q* | 5,238 |
| | 608,026 | | 262,498 | | 474,397 | | 539,948 | | 393,114 | | 465,464 |

| Names of Parts. | One Central Span of 300 Metres. | Two Cantilever Arms of 187·5 Metres each. |
|---|---|---|
| | Tons. | Tons. |
| **Main girders** . . . . . . . . . . . | **5,379,684** | **5,594,104** |
| **Secondary bars of the main girders** . . . . . | **67,336** | **55,632** |
| **Plates, rails, footways, and bracings of sleepers** . . | **411,732** | **501,560** |
| **Longitudinals under rails** . . . . . . . . | **335,040** | **380,680** |
| **Beams** . . . . . . . . . . . . | **106,824** | **97,002** |
| **Lower bracing** . . . . . . . . . . | **270,468** | **431,144** |
| **Inclined bracing** . . . . . . . . . . | **45,584** | **41,006** |
| | **6,616,668** | **7,101,128** |
| **Sum total** . . . . . | **13,717,796** | |

2. *Central Girder of* 125 *Metres.*



| Lower Members. | | Upper Members. | | Tension Members. | |
|---|---|---|---|---|---|
| | Tons. | | Tons. | | Tons. |
| J | 2,353 | J′ | 3,827 | *y* | 9,968 |
| $K_1$ | 2,880 | K′ | 7,409 | *r* | 2,715 |
| $K_2$ | 2,327 | L′ | 11,911 | *s* | 2,839 |
| $L_1$ | 3,977 | | | *t* | 2,464 |
| $L_2$ | 4,375 | | | *u* | 1,158 |
| $M_1$ | 5,812 | | | *v* | 1,857 |
| | | | | *w* | 0,571 |
| | 21,724 | | 23,147 | | 21,572 |

| | Tons. |
|---|---|
| Main girders | 265,772 |
| Secondary bars of principal girders | 11,790 |
| Plates, rails, footways, bracings of sleepers | 162,584 |
| Longitudinals under rails | 102,720 |
| Beams | 24,114 |
| Lower bracing | 16,864 |
| Upper bracing | 13,488 |
| Inclined bracing | 8,862 |
| Total | 606,194 |

### 3. *Two Metal Piers.*

| | Tons. |
|---|---|
| Interior stiffening of lower members of flooring girders | 60 |
| Supporting contrivance | 764 |
| Metal columns | 2,268 |
| Bracing of columns | 332 |
| Anchor tubes | 240 |
| Anchor bolts | 360 |
| Total | 4,024 |

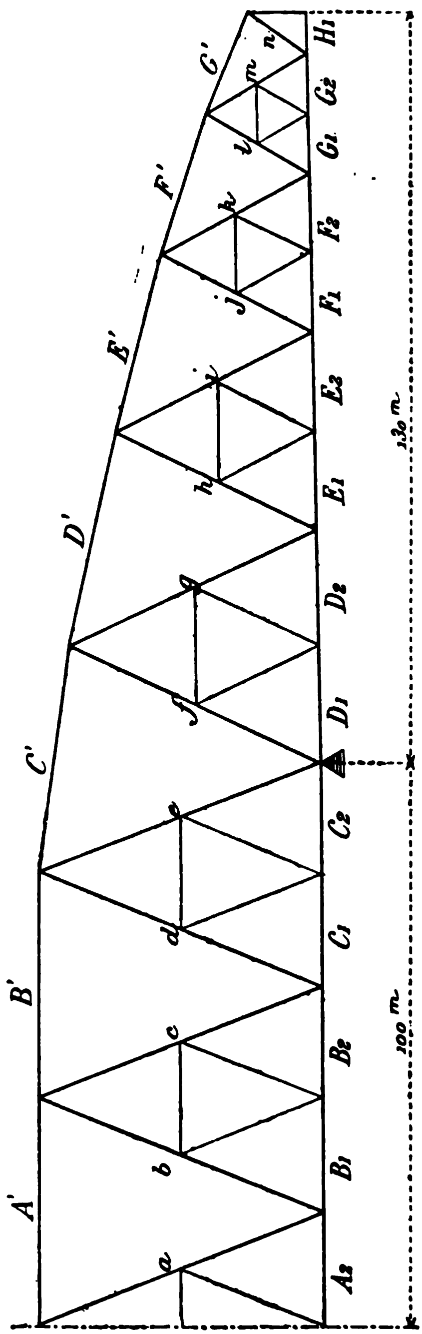
### *Summary.*

| | Tons. |
|---|---|
| Metal flooring (1° + 2°) | 14,324 |
| Piers (3°) | 4,024 |
| Total | 18,348 |

Weight per metre of column: $\frac{18,348}{800}$ = about 23 tons.

## § 2. Spans of 200 Metres and 350 Metres.

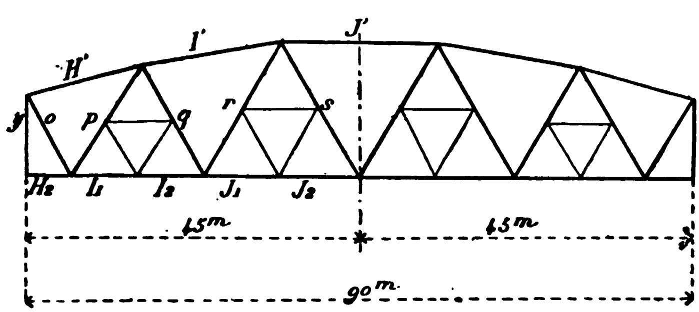
### 1. *Central Span and Cantilever Arms.*



| Central Span. | | | | | | Cantilever Arms. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Lower Members. | | Upper Members. | | Tension Members. | | Lower Members. | | Upper Members. | | Tension Members. | |
| | Tons. | | Tons. | | Tons. | | Tons. | | Tons. | | Tons. |
| $A_2$ | 38,708 | A' | 46,020 | *a* | 13,338 | $D_1$ | 59,025 | C' | 74,248 | *f* | 50,989 |
| $B_1$ | 42,419 | B' | 53,078 | *b* | 18,139 | $D_2$ | 53,881 | D' | 44,507 | *g* | 44,228 |
| $B_2$ | 44,611 | | | *c* | 25,359 | $E_1$ | 30,702 | E' | 23,020 | *h* | 24,638 |
| $C_1$ | 54,816 | | | *d* | 41,695 | $E_2$ | 27,611 | F' | 10,625 | *i* | 22,353 |
| $C_2$ | 59,052 | | | *e* | 63,399 | $F_1$ | 14,002 | G' | 2,769 | *j* | 11,317 |
| | | | | | | $F_2$ | 12,175 | | | *k* | 11,108 |
| | | | | | | $G_1$ | 4,724 | | | *l* | 5,048 |
| | | | | | | $G_2$ | 3,800 | | | *m* | 6,475 |
| | | | | | | $H_1$ | 1,947 | | | *n* | 3,689 |
| | 239,606 | | 99,098 | | 161,930 | | 207,867 | | 155,169 | | 179,845 |

| Description of Parts. | One Central Span of 200 Metres. | Two Overhanging Trusses of 130 Metres each. |
|---|---|---|
| | Tons. | Tons. |
| Main girders . . . . . . . . | 2,002,536 | 2,171,524 |
| Secondary bars of main girders . . . . . . | 40,000 | 30,300 |
| Plates, rails, footways, bracings of longitudinals . | 268,752 | 344,384 |
| Longitudinals under rails . . . . . . . | 207,520 | 263,400 |
| Beams . . . . . . . . . . . | 67,920 | 66,396 |
| Lower bracings . . . . . . . . . | 67,840 | 154,454 |
| Inclined bracings. . . . . . . . . . | 33,300 | 29,192 |
| | 2,687,868 | 3,059,650 |
| Sum total . . . . . | 5,747,518 | |

2. *Central Girder of* 90 *Metres.*



| Lower Members. | | Upper Members. | | Tension Members. | |
|---|---|---|---|---|---|
| | Tons. | | Tons. | | Tons. |
| $H_2$ | 1,067 | H' | 1,874 | *y* | 0,868 |
| $I_1$ | 1,558 | I' | 3,899 | *o* | 2,715 |
| $I_2$ | 1,265 | J' | 2,411 | *p* | 1,711 |
| $J_1$ | 2,381 | | | *q* | 1,680 |
| $J_2$ | 2,472 | | | *r* | 0,338 |
| | | | | *s* | 0,902 |
| | 8,743 | | 8,184 | | 8,214 |

| | Tons. |
|---|---|
| Main girders . . . . . . . . . . . . . | 100,564 |
| Secondary bars of main girders . . . . . . . | 8,431 |
| Footplates, rails, footways, bracings of longitudinals . . | 116,776 |
| Longitudinals under rails . . . . . . . . | 84,944 |
| Beams . . . . . . . . . . . . . | 19,184 |
| Lower bracing . . . . . . . . . . . | 9,990 |
| Upper bracing . . . . . . . . . . . | 7,984 |
| Inclined bracing . . . . . . . . . . | 5,442 |
| Total . . . . . . | 353,315 |

## 3. *Two Metal Piers.*

| | Tons. |
|---|---|
| Inner framings of lower members of floor girders . . . . | 28 |
| Supporting machinery . . . . . . . . . . | 422·8 |
| Metal columns . . . . . . . . . . . . | 1,625·2 |
| Bracings of columns . . . . . . . . . . | 248 |
| Anchor tubes . . . . . . . . . . . . | 180 |
| Anchor bolts . . . . . . . . . . . . | 340 |
| Total . . . . . . | 2,844 |

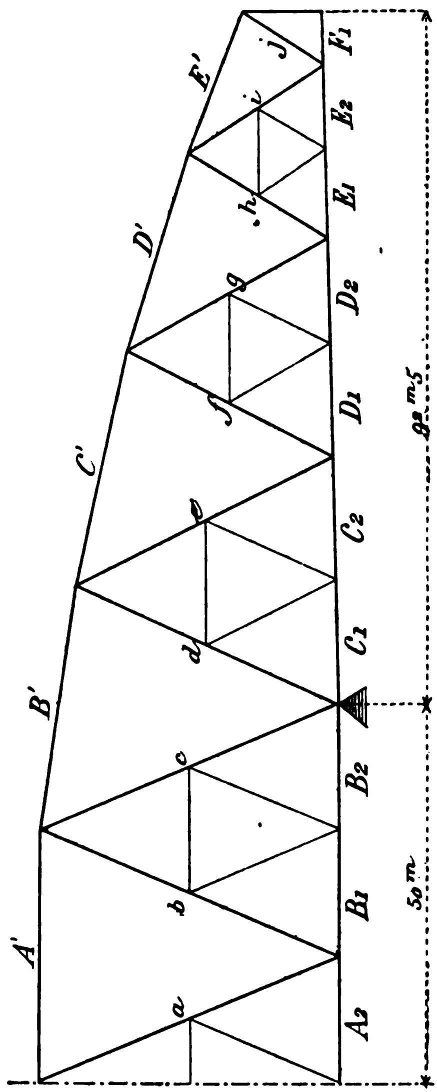
## *Summary.*

| | Tons |
|---|---|
| Metal flooring (1° + 2°) . . . . . . . . . . | 6,101 |
| Piers (3°) . . . . . . . . . . . . | 3,844 |
| Total . . . . . . | 8,945 |

Weight per running metre: $\frac{8,945}{500}$ = about 16·3 tons.

## § 3. SPANS OF 100 METRES AND 250 METRES.

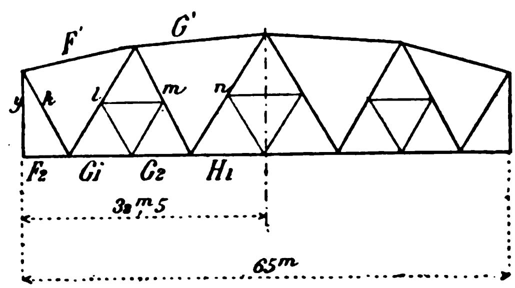
### 1. *Central Span and Cantilever Arms.*



| Central Span. | | | | | | Cantilever Arms. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Lower Members. | | Upper Members. | | Tension Members. | | Lower Members. | | Upper Members. | | Tension Members. | |
| | Tons. | | Tons. | | Tons. | | Tons. | | Tons. | | Tons. |
| $A_2$ | 27,252 | A′ | 32,598 | *a* | 4,684 | $C_1$ | 27,536 | B′ | 35,698 | *d* | 24,712 |
| $B_1$ | 28,748 | | | *b* | 11,117 | $C_2$ | 24,764 | C′ | 20,562 | *e* | 21,596 |
| $B_2$ | 29,972 | | | *c* | 21,394 | $D_1$ | 13,406 | D′ | 9,476 | *f* | 11,635 |
| | | | | | | $D_2$ | 11,652 | E′ | 2,250 | *g* | 10,665 |
| | | | | | | $E_1$ | 4,646 | | | *h* | 4,730 |
| | | | | | | $E_2$ | 3,683 | | | *i* | 5,660 |
| | | | | | | $F_1$ | 1,287 | | | *j* | 2,753 |
| | 85,972 | | 32,598 | | 37,195 | | 86,974 | | 67,986 | | 81,751 |

| Description of Parts. | One Central Span of 100 Metres. | Two Cantilever Arms of 92·5 Metres each. |
|---|---|---|
| | Tons. | Tons. |
| Main girders . . . . . . . . . . . | 623,060 | 946,844 |
| Secondary bars of main girders . . . . . | 12,900 | 15,164 |
| Plates, rails, footways, bracing of sleepers . . . | 133,500 | 243,340 |
| Longitudinals under rails . . . . . . . | 101,184 | 176,280 |
| Beams . . . . . . . . . . . . | 27,600 | 42,952 |
| Lower bracing . . . . . . . . . . | 16,326 | 69,040 |
| Inclined bracings . . . . . . . . . . | 22,000 | 15,000 |
| | 936,570 | 1,508,620 |
| Sum total . . . | 2,145,190 | |

2. *Central Girder of* 65 *Metres.*



| Lower Members. | | Upper Members. | | Tension Members. | |
|---|---|---|---|---|---|
| | Tons. | | Tons. | | Tons. |
| $F_2$ | 0,628 | F' | 1,101 | *y* | 0,564 |
| $G_1$ | 0,792 | G' | 2,121 | *k* | 1,312 |
| $G_2$ | 0,773 | | | *l* | 0,938 |
| $H_1$ | 2,283 | | | *m* | 1,001 |
| | | | | *n* | 0,202 |
| | 4,476 | | 3,222 | | 4,017 |

| | Tons. |
|---|---|
| Main girders . . . . . . . . . . . . . . . | 46,860 |
| Secondary bars of main girders . . . . . . . . . | 5,770 |
| Footplates, rails, footways, bracing of longitudinals . . . . | 84,336 |
| Longitudinals under rails . . . . . . . . . . | 57,696 |
| Beams . . . . . . . . . . . . . . . | 15,648 |
| Lower bracing . . . . . . . . . . . . . | 7,650 |
| Upper bracing . . . . . . . . . . . . . | 5,714 |
| Inclined bracing . . . . . . . . . . . . | 5,442 |
| Total . . . | 229,116 |

### 3. *Two Metal Columns.*

| | Tons. |
|---|---|
| Inner framings of lower members of flooring girders . . . . | 12 |
| Supporting gear . . . . . . . . . . . . . | 240 |
| Metal piers . . . . . . . . . . . . . . | 1,448 |
| Bracings of piers . . . . . . . . . . . . | 140 |
| Anchor tubes . . . . . . . . . . . . . | 112 |
| Anchor bolts . . . . . . . . . . . . . | 220 |
| Total . . . | 2,172 |

### *Summary.*

| | Tons. |
|---|---|
| Metal flooring (1° + 2°) . . . . . . . . . . . | 2,674 |
| Piers (3°) . . . . . . . . . . . . . . | 2,172 |
| Total . . . | 4,846 |

Weight of the running metre: $\frac{4846}{350}$ = 13·8 tons, approximately.

## § 4. General Summary.

| Number of Spans for the whole of the Bridge. | Description of Spans. | Units. | | Totals. | |
|---|---|---|---|---|---|
| | | Lengths. | Weights. | Lengths. | Weights. |
| | | Metres. | Tons. | Metres. | Tons. |
| 32 | Spans of 300 and 500 metres | 800 | 18,348 | 25,600 | 587,136 |
| 13 | " 200 and 350 " | 550 | 8,945 | 7,150 | 116,285 |
| 14 | " 100 and 250 " | 350 | 4,846 | 4,900 | 67,844 |
| | Totals for whole bridge . . . | | | 37,658 | 771,265 |

Average weight per linear metre of bridge: $\frac{771,265}{37,650}$ = 20·5 tons.

## VIII.—CALCULATIONS OF RESISTANCE.

The calculations relating to the large spans of 300 and 500 metres will alone be here reproduced, the same method having been followed for the three other types of spans.

### § 1. The Central Girder.

#### 1. *Longitudinals under Rails.*

The two lines of rails are carried by four rows of longitudinals laid underneath the rails.

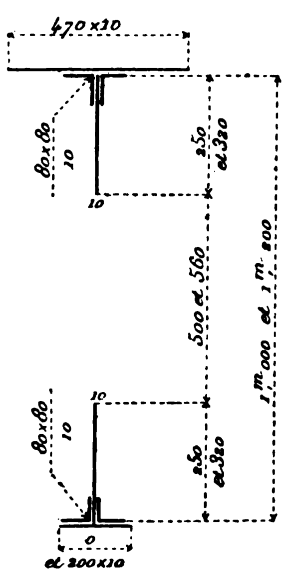
Their length varies from 6·50 metres to 14 metres.

The loads comprise:—

The weight of the rails, of the footplates, of the footways, and of the bracings of the longitudinals.

The weight of the longitudinals proper is supposed to vary with the weight under consideration.

And the additional load due to passing trains.




This additional load is assumed to be uniformly distributed according to the regulations of the 9th July 1877.

All the longitudinal beams are box-latticed.

The accompanying sketch shows their shape in cross section.

The bars of the lattice work are formed of T irons of $\frac{100 \times 60}{8 \times 8}$ and of $\frac{100 \times 61}{9 \times 8}$.

The results of the calculations of the longitudinal beams underlying the rails are contained in the following table. They have been arrived at on the assumption that the beams will be supported at the ends only:—

| Number of Beams in a Row. | Length of Beams. | FOOTPLATES, RAILS, &c. — Weight per Running Metre of Beam. | Weight of Beam. | Weight of Bed-plates under Rails, &c. | Weight of Beams. |
|---|---|---|---|---|---|
| | Metres. | Kilos. | Kilos. | Kilos. | Kilos. |
| 2 | 6·50 | 324·37 | 1,402 | 4,217 | 2,804 |
| 4 | 9·25 | 324·37 | 1,842 | 12,002 | 7,368 |
| 4 | 11·75 | 324·37 | 2,148 | 15,245 | 8,592 |
| 2 | 14·00 | 327·94 | 3,458 | 9,182 | 6,916 |
| Total per row of beams . . . . | | | | 40,646 | 25,680 |

Thus, for the four rows of the whole bridge, the weights are as follows:—

| | Tons. |
|---|---|
| Bed-plates, rails, footways, bracings of beams . . . . | 162,584 |
| Longitudinals under rails . . . . . . . . | 102,720 |

## 2. *Beams.*

The cross beams are the immediate support of the sleepers underlying the rails.

They assume the shape of Warren girders with three panels or bays; their height varies between 3·60 metres and 3·40 metres, and their length of span between 9 metres and 8·50 metres.

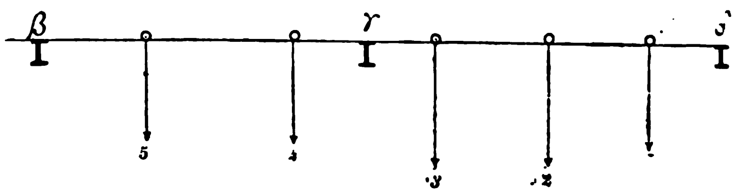
Leaving out of consideration the weight of the cross beams themselves, it will be found that they will only have to support those distinct loads which will be transmitted to them through the medium of the sleepers underlying the rails.

Thus there is, in the first place, the load given through the plates, rails, &c., and that of the longitudinals themselves. The table given enables these loads to be determined. As to the weight of the trains, it will vary according to their position and nature.

Let us call any given beam $\gamma$, the two adjacent ones $\beta$ and $\delta$, and suppose that the rolling loads comprised between $\beta$ and $\delta$ are 1, 2, 3, 4, 5.

M. Bertrand de Fontviolant has shown that if $\beta$, $\gamma$, and $\gamma$, $\delta$, be

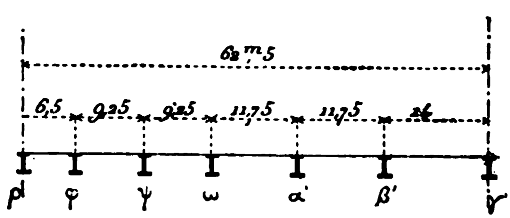
considered as two non-continuous girders, the position of the train to which the maximum of reaction of support $\gamma$ corresponds, is the



same as that which produces the maximum moment of flexure under section $\gamma$ of the beam sustaining the same loads, and resting upon the two supports $\beta$ and $\delta$ only.

Applying, therefore, Weyrauch's construction, one is enabled immediately to find the most unfavourable position of the train, whether of simple or double traction, and to calculate the load transmitted to the beam. The results of such calculation are as follows:—

| Beams. | Maximum Stress (for each Weight). | Case in which the Maximum Stress is exercised. |
|---|---|---|
| | Tons. | |
| $\rho$ . . . . | 42 | Simple traction train. |
| $\phi$ . . . . | 43 | do. |
| $\psi$ . . . . | 47 | do. |
| $\omega$ . . . . | 50 | do. |
| $\alpha'$ . . . . | 54 | do. |
| $\beta'$ . . . . | 55 | do. |
| $\gamma'$ . . . . | 59 | do. |



Supposing all the loads supported by each member to be concentrated at its two upper apices, the science of statics enables us to determine the strains that will be developed in each of these elements, and the corresponding weights.

The following figures will thus be arrived at :—

| | Kilogrammes. |
|---|---|
| Weight of one beam $\rho$ | 1·629 |
| ,, ,, $\phi$ | 1·622 |
| ,, ,, $\psi$ | 1·746 |
| ,, ,, $\omega$ | 2·022 |
| ,, ,, $\alpha'$ | 2·016 |
| ,, ,, $\beta'$ | 1·968 |
| ,, ,, $\frac{1}{2}\gamma'$ | 1·054 |
| Total | 12·057 |

Hence the weight of all the members of one whole span may be expressed thus—

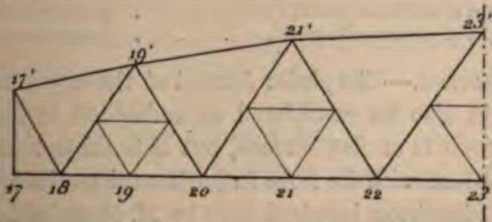
$$2 \times 12{,}057 \text{ tons} = 24{,}114 \text{ tons.}$$

### 3. *Wind Bracings.*

To determine the stresses due to the action of wind, it has been assumed that the pressures exercised upon all the parts of the superstructure would be transmitted to the upper and lower apices of the main girders.

To calculate these pressures, all those surfaces of the girder exposed to the wind, considered as plain, the surface of the longitudinals and of the train (in the case of the bridge being loaded), and the surface of the web of the girder exposed to the wind, less the portion concealed by the longitudinals and the train, have been considered, and it has moreover been assumed that the wind may attain a force of 170 kilogrammes per square metre at a time when the span is loaded, and 270 kilogrammes per square metre when the span is free from any load.

By these means loads have been obtained for the different apices for half of a span.



| Lower Apices. | Span Loaded. | Span Unloaded. | Upper Apices. | Span Loaded. | Span Unloaded. |
|---|---|---|---|---|---|
| | Tons. | Tons. | | Tons. | Tons. |
| 17 | 4,989 | 5,507 | 17' | 6,211 | 11,180 |
| 18 | 12,917 | 14,707 | 19' | 14,037 | 24,742 |
| 19 | 11,708 | 11,102 | 21' | 21,564 | 36,116 |
| 20 | 20,596 | 26,386 | 23' | 13,217 | 21,966 |
| 21 | 15,645 | 15,404 | ... | ... | ... |
| 22 | 27,484 | 35,334 | ... | ... | ... |
| 23 | 9,979 | 10,238 | ... | ... | ... |

Lower Bracing.—The whole of the lower chords of the principal girders and of the cross-shaped bracings which connect them form a girder sustaining the strains transmitted to the lower apices. This girder may be considered as imbedded in a recess at both ends. The diagrams (No. 20) show how the moments of flexure and of shearing stress have been determined.

From these the stresses developed in the chords and in the bars of the bracings, as well as the corresponding weights can be worked out.

| Chords. | Stress in one Chord. | Length of one Chord. | Weight of one Chord. | Panels including the Bars. | Stress on the two Bars. | Length of one Bar. | Weight of two Bars. |
|---|---|---|---|---|---|---|---|
| | Tons. | Metres. | Tons. | | Tons. | Metres. | Tons. |
| J | 220,5 | 6,50 | 1,099 | (17, 18) | 142,2 | 11,927 | 1,301 |
| $K_1$ | 154,5 | 9,25 | 1,096 | (18, 19) | 155,0 | 13,623 | 1,620 |
| $K_2$ | 76,5 | 9,25 | 0,543 | (19, 20) | 134,8 | 13,623 | 1,409 |
| $L_1$ | 55,5 | 11,75 | 0,500 | (20, 21) | 135,0 | 15,431 | 1,598 |
| $L_2$ | 99,6 | 11,75 | 0,898 | (21, 22) | 100,0 | 15,431 | 1,184 |
| $M_1$ | 114,0 | 14,00 | 1,224 | (22, 23) | 100,0 | 17,205 | 1,320 |
| | Total . . | | 5,360 | | Total . . | | 8,432 |

The following weights will thus be obtained for the whole span:—

| | Tons. |
|---|---|
| Weight of the lower chords . . . . | $4 \times 5,360 = 21,440$ |
| Weight of the lower bracing . . . . | $2 \times 8,432 = 16,861$ |

Upper Bracing.—The girder formed of the upper members and braces should also be considered as embedded in recesses at the ends. The web is of flat surface, but it is subject to the normal strains consistent with its form in horizontal sections.

Thi[illegible] ito by M. Maurice Lévy, and one

of the drawings (No. 18) was based on the formula of the analytic theory he had proposed. This theory gives the moments of flexure and torsion and the shearing stresses, determined according to the directions of the braces.

The following tables summarise the results arrived at:—

| Members. | Strain upon one Member. | Length of one Member. | Weight of one Member. | Panel, including Inclined Members. | Stress upon the two Inclined Members. | Length of one Inclined Member. | Weight of two Inclined Members. |
|---|---|---|---|---|---|---|---|
| | Tons. | Tons. | Tons. | | Tons. | Metres. | Tons. |
| J′ | 161·4 | 16,269 | 2,014 | (17′, 19′) | 156·8 | 18,651 | 2,243 |
| K′ | 98·4 | 21,288 | 1,607 | (19′, 21′) | 133·5 | 23,260 | 2,382 |
| L′ | 156·0 | 25,798 | 3,087 | (21′, 23′) | 100·0 | 27,624 | 2,119 |
| | Total . . | | 6,708 | | Total . . | | 6,744 |

The following weights, therefore, apply to the whole span:—

| | Tons. |
|---|---|
| Weight of the top member . . . . | $4 \times 6,708 = 26,832$ |
| Weight of the top bracing . . . . | $2 \times 6,744 = 13,488$ |

Inclined Bracings.—When once the moments of torsion are known, it becomes possible to determine the stresses in the bars of the inclined bracings. The torsion stress, however, being very insignificant, the weights thus found with regard to the bars are inadmissible. Supposing these bars are of a size compatible with their shape, their total weight will be 8862 tons.

## 4. *Inclined Members* (*Braces of Main Girders*).

The secondary bars, with a portion of the main bars, form heavier girders with three bays. A simple application of statics is therefore sufficient to enable the stresses to be determined which these bars will have to withstand, supposing that the loads they will have to support directly are known.

The weight of the secondary members throughout the span will therefore be 11,790 tons.

## 5. *Main Girders.*

The length of each main girder is 125 metres. The load hey have to support is formed of the weight of the girders them-

selves, the weight of the metal flooring, and of additional loads. A variety of experiments show that these loads may be regarded as uniformly distributed and applied to the lower portion of the girders.

Let

$p$ be the total per square metre of the main girder.

P the weight of a girder such as it should be to resist vertical strains.

$p'$ the weight per running metre of girder for all parts under consideration; and

$p''$ the additional load per running metre of girder.

We then obtain—

$$p = \frac{P}{L} + p' + p'' \quad (1)$$

Or let

$t$ be the tension or compression of one girder bar per unit of load and per running metre.

$l$ the length of the bar.

$\pi$ the density of the metal.

R the co-efficient of resistance per unit of surface.

The weight of a bar will then be:—

$$1{\cdot}18 \frac{\pi}{R} ptl.$$

The factor 1·18 being allowed for rivetings, joints, and fittings, the weight of one girder will then be:—

$$P = 1{\cdot}18 \frac{\pi}{R} p \, \Sigma \, tl \quad (2)$$

Eliminating $p$ between formulæ (1) and (2), we find:

$$\frac{P}{L} = 1{\cdot}18 \, \pi + \frac{(p' + p'') \, \Sigma \, tl}{RL - 1{\cdot}18 \, \pi \, \Sigma \, tl} \quad (3)$$

CALCULATION OF $(p' + p'')$.—If we summarise the weights of all the pieces known, we obtain:

| | Tons. |
|---|---|
| Plates, rails, footways, &c. . . . . . . . | 162,584 |
| Longitudinals under rails . . . . . . . | 102,720 |
| Beams . . . . . . . . . . | 24,114 |
| Members of lower bracing . . . . . . . | 16,864 |
| Members of upper bracing . . . . . . . | 13,488 |
| Members of inclined bracings . . . . . . . | 8,862 |
| Secondary bars of main girders . . . . . . | 11,790 |
| Weight of members required to enable them to resist the action of the wind . . . . . . . . | 48,272 |
| | 388,694 |

The weight per metre throughout will be:

$$p' = \frac{388,694}{2 + 125} = 1,555 \text{ tons.}$$

The overcharge ($p''$) per metre throughout of girder = 3 tons. Hence:

$$p' + p'' = 1,555 \text{ tons} + 3 \text{ tons} = 4,555 \text{ tons.}$$

CALCULATION OF $\Sigma\ tl$.—The form of a girder being unalterable under strain, the stresses acting upon each member may be determined by a figure representing the form of the girder.

The tracing on Sheet 18 is based on the assumption of a load of one ton per metre throughout.

The following table gives the figures of $t$, of $l$, and of $tl$, for each member:—

| Members. | $t$. | $l$. | $tl$. | Inclined Members. | $t$. | $l$. | $tl$. |
|---|---|---|---|---|---|---|---|
| | | Metres. | | | | Metres. | |
| J | 55,2 | 6,50 | 358,800 | $y$ | 62,5 | 5,72 | 357,500 |
| K | 55,2 | 18,50 | 1,021,200 | $r$ | 60,8 | 12,78 | 777,024 |
| L | 84,7 | 23,50 | 1,990,450 | $s$ | 46,1 | 17,63 | 812,743 |
| M | 93,8 | 14,00 | 1,313,200 | $t$ | 40,0 | 17,63 | 705,200 |
| J' | 31,9 | 16,27 | 519,013 | $u$ | 15,1 | 21,96 | 331,596 |
| K' | 78,0 | 21,29 | 1,660,620 | $v$ | 24,2 | 21,96 | 531,432 |
| L' | 97,9 | 25,80 | 2,525,820 | $w$ | 6,7 | 24,41 | 163,547 |
| | Total . . | | 9,389,103 | | Total . . | | 3,679,042 |

Thus for one whole girder we obtain:

$$\Sigma tl = 2 + (9,389,103 + 3,679,042) = 26,136.$$

By these means all the quantities are known that are included in the second number of formula (3), namely :—

$$p' + p'' = 4{,}555 \text{ tons.}$$
$$\Sigma\, tl = 26{\cdot}136$$
$$R = 12 \times \overline{10}^6$$
$$\Pi = 7{\cdot}800$$
$$L = 125$$

hence:

$$\frac{P}{L} = 0{\cdot}87 \text{ tons.}$$

The weight of the two girders, necessary to enable them to withstand vertical stresses, is therefore:—

$$2 \times 125 \times 0{\cdot}87 \text{ tons} = 217{,}500 \text{ tons.}$$

Adding to it the weight necessary to withstand the action of the wind, we obtain:—

$$217{,}500 \text{ tons} + 48{,}272 \text{ tons} = 265{,}772.$$

## § 2. Central Span and Cantilever Arms.

### 1. *Longitudinal Beams under Rails.*

The length of span of the longitudinals varies from 7·50 metres to 25 metres.

Their arrangement being the same as that of the corresponding members of the central girder, the results only of the calculations will be here indicated.

| Description of Span. | Number of Longitudinals in a Row. | Length of Longitudinals. | Plates, Rails, &c., Weight per Average Metre of Sleeper. | Weight of one Longitudinal. | Weight of Plates, Rails, &c. | Weight of Longitudinals. |
|---|---|---|---|---|---|---|
| | | Metres. | Kilos. | Kilos. | Kilos. | Kilos. |
| Central span . . | 12 | 25,00 | 343,11 | 6·980 | 102·933 | 83·760 |
| Total for one row of sleepers . . | | | | | 102·933 | 83·760 |
| Cantilever arms . . | 4 | 25,00 | 343,11 | 6,980 | 34·311 | 27·920 |
| | 4 | 21,50 | 335,94 | 5,825 | 28·891 | 23·300 |
| | 4 | 18,00 | 333,74 | 4,434 | 24·029 | 17·736 |
| | 4 | 14,50 | 327,94 | 3,349 | 19·021 | 13·396 |
| | 4 | 11,00 | 324,37 | 2,431 | 14·272 | 9·724 |
| | 2 | 7,50 | 324,37 | 1,547 | 4·866 | 3·094 |
| Total for one row of longitudinals . | | | | | 125·390 | 95·170 |

For the four rows of longitudinals we will thus have—

| Description. | Central Span of 300 Metres. | Two Cantilever Arms of 187·5 Metres each. |
|---|---|---|
| | Tons. | Tons. |
| Plates, rails, footways, and bracings of longitudinals | 411,732 | 501,560 |
| Longitudinals underlying rails . . . . . | 335,040 | 380,680 |

## 2. *Beams.*

The inclined members of the central span and of the cantilever arms are of the same shape as those of the central girder.

Their length varies between 23 and 9 metres, and their height from 7·60 to 3·60 metres.

The loads due to the plates, rails, &c., and the weight of the sleepers are found with the assistance of the following tables.

As regards the strain due to the passing trains, the sketch on p. 107 indicates the maximum attained in the case of each train.

| Tension Members. | Maximum Strain (for one Line). | Case in which the Maximum may be attained. | Tension Members. | Maximum Strain (for one Line). | Case in which the Maximum is attained. |
|---|---|---|---|---|---|
| | Tons. | | | Tons. | |
| $\eta'$ | 89 | Double traction train. | $\eta$ | 66 | Simple traction train. |
| $\alpha$ | 89 | do. | $\theta$ | 60 | do. |
| $\beta$ | 85 | do. | $\lambda$ | 58 | do. |
| $\gamma$ | 81 | do. | $\mu$ | 52 | do. |
| $\delta$ | 76 | do. | $\nu$ | 48 | do. |
| $\epsilon$ | 71 | do. | $\rho$ | 42 | do. |

In addition to this, the tension members will have to sustain two kinds of strains, the one due to the action produced by the wind upon the train and the sleepers, and the other caused by the inclination of the main girders, which will be more fully referred to farther on.

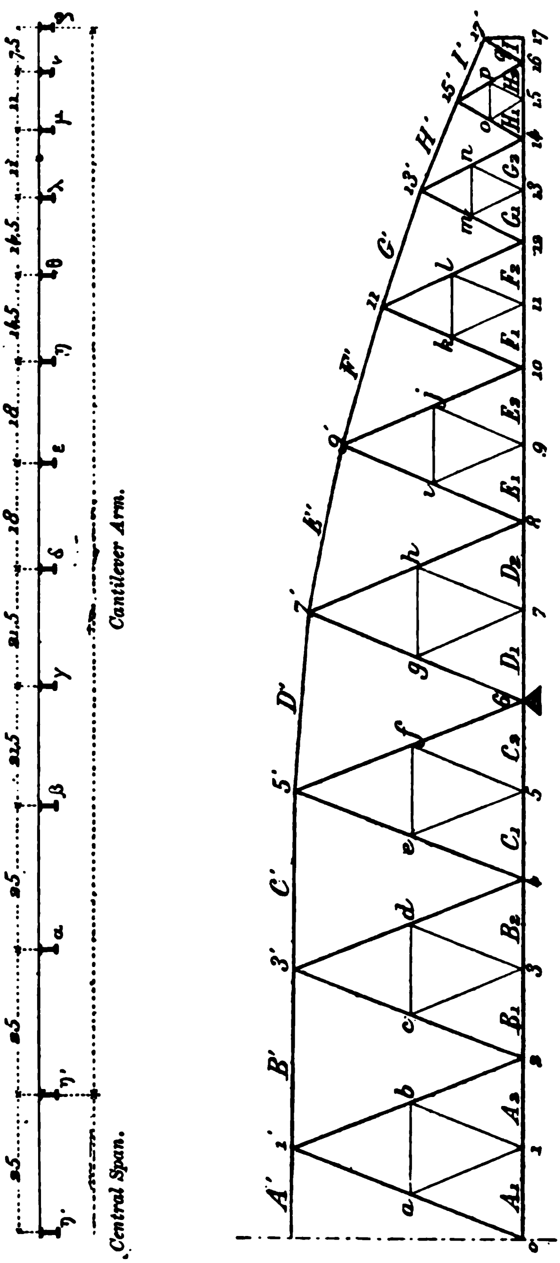
The weights attained in this connection are recorded in the following table:—

| Description of Spans. | Tension Members. | Weight on each. | Number of Tension Members. | Total Weight. |
|---|---|---|---|---|
| | | Kilos. | | Tons. |
| Central span of 300 metres . . . | $\eta'$ | 8,902 | 12 | 106·824 |
| | | | Total . . | 106·824 |
| Two cantilever arms of 187·5 metres each | $\eta'$ | 8,902 | 1 | 8·902 |
| | $\alpha$ | 7,838 | 2 | 15·676 |
| | $\beta$ | 6,776 | 2 | 13·552 |
| | $\gamma$ | 6,070 | 2 | 12·140 |
| | $\delta$ | 5,114 | 2 | 10·228 |
| | $\epsilon$ | 4,182 | 2 | 8·364 |
| | $\eta$ | 3,500 | 2 | 7·000 |
| | $\theta$ | 2,814 | 2 | 5·628 |
| | $\lambda$ | 2,402 | 2 | 4·804 |
| | $\mu$ | 2,138 | 2 | 4·276 |
| | $\nu$ | 1,718 | 2 | 3·436 |
| | $\rho$ | 1,498 | 2 | 2·996 |
| | | | Total. . . | 97·000 |

### 3. *Bracings.*

The surfaces exposed to the action of the wind have been determined in the same way as in the case of the central girder, and the force of the wind has been supposed to be the same.

It has been assumed that the loads at each apex are due to the braces that are there united to the top or bottom member. Thus the different apices would have to sustain the following pressures :—


Central Span.
Cantilever Arm.

| Upper Apices. | Case of Loaded Bridge. | Case of Unloaded Bridge. |
|---|---|---|
| | Tons. | Tons. |
| 1' | 60,182 | 95,583 |
| 3' | 60,182 | 95,583 |
| 5' | 59,978 | 93,978 |
| 7' | 59,300 | 93,000 |
| 9' | 58,752 | 92,359 |
| 11' | 52,569 | 90,432 |
| 13' | 38,203 | 61,656 |
| 15' | 24,428 | 40,702 |
| 17' | 9,125 | 10,290 |

| Lower Apices. | Case of Bridge Loaded. | | Case of Bridge not Loaded. | |
|---|---|---|---|---|
| | Loads applied Direct. | Loads due to Sleepers and Trains. | Loads applied Direct. | Loads due to Longitudinals. |
| | Tons. | Tons. | Tons. | Tons. |
| 0 | 40,768 | 11,050 | 66,962 | 7,425 |
| 1 | 26,908 | 22,100 | 34,506 | 14,850 |
| 2 | 81,534 | 22,100 | 133,926 | 14,850 |
| 3 | 26,908 | 22,100 | 34,506 | 14,850 |
| 4 | 81,534 | 22,100 | 133,926 | 14,850 |
| 5 | 26,908 | 22,100 | 34,506 | 14,850 |
| 6 | 70,473 | 22,100 | 125,506 | 14,850 |
| 7 | 24,557 | 22,100 | 40,666 | 14,850 |
| 8 | 62,118 | 20,188 | 99,810 | 13,220 |
| 9 | 17,816 | 18,275 | 29,713 | 11,610 |
| 10 | 41,331 | 16,329 | 72,130 | 9,936 |
| 11 | 12,723 | 14,382 | 21,250 | 8,262 |
| 12 | 27,622 | 12,614 | 49,393 | 6,872 |
| 13 | 8,887 | 10,846 | 14,426 | 5,481 |
| 14 | 18,595 | 9,350 | 32,171 | 4,523 |
| 15 | 6,091 | 7,854 | 9,628 | 3,564 |
| 16 | 11,298 | 6,650 | 16,002 | 2,997 |
| 17 | 2,798 | 2,878 | 4,712 | 1,215 |

Owing to the absence of bracings at the upper portion of the girders, it is the lower bracing that will have to resist the action of the wind.

The stresses due to the trains and to the sleepers, as well as those applied to the top apices, will therefore have to be transmitted to the lower apices.

But in order to obtain a system of forces equivalent to the first system it will be necessary to add to these forces conveyed to

ie lower nodes such couples as will equal the moments of such orces about their new points of application.

The effects of such couples will be these:—

The strains due to the longitudinals under the rails and to the rain are transmitted to the lower apices by means of the cross beams.

This transmission develops, in the web of the girders, tensions nd compressions which have been taken into account in calculaing their weights.

Let $Ph$ be the value of one couple due to the action of the wind pon the longitudinals and the train.

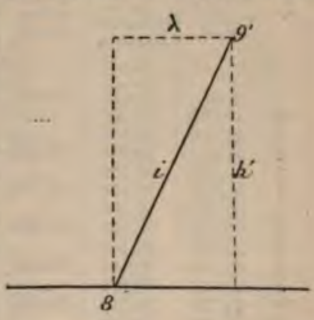
If $l$ be the distance between the apices of the main girders, it rill be seen that the couple $Ph$ will load one of the girders with quantity equal to

$$\frac{Ph}{l},$$

rhile the second girder will be relieved of the same quantity.

As to the stress on the top apices, it has been supposed that iey are transmitted to the lower apices by the rigid structure comosed of the compression members of the girders and the inclined racings connecting them by pairs.

Let us suppose, for example, that the force $P'$ is applied apex 9′. From the foregoing considerations it is clear that will be transmitted to apex 8 by ompression members $i$ of the two irders, and by the braces connecting hese two bars.




This couple is equal to the product of $P'$ multiplied by the distance between the apices 9′ and 8. It will be seen that it can be decomposed into two other couples.

The one $P'h'$ loading one of the girders with $\frac{P'h'}{l}$ and the other $P'\lambda$ producing in the members a tension and a compression equal to

$$\frac{P'\lambda}{l}$$

LOWER BRACING.—The whole of the lower members of the

principal girders, the lower bars of the tension and compression members and cross-shaped bracings, gives the form of girder which is to sustain the stresses transmitted to the lower apices (see sheet 20).

It has been shown just now what stresses would act upon each of the lower apices. To these must be added the effect of wind upon the independent span of 125 metres.

These effects are, $158{,}347^{T}$ when the bridge is loaded,
and 212,682 „ „ free.

They must be applied to apex 17, that is, at the end of the cantilever.

To these effects we must further add couples similar to those mentioned above. The effect of these couples is to load vertically the main girders with a weight equal to—

$124{,}698^{T}$ when the bridge is loaded,
and 167,545 „ „ free.

These, however, will only have to be considered in calculations referring to the heavier trains.

In the case of the lower bracing, there will have to be considered at the end of the cantilever a moment of flexure equal to and acting in the opposite direction to the moment at the junctions of the lower bracing of the central girder.

| Apices. | Case of Bridge Loaded. | | | | Case of Bridge Free. | | | |
|---|---|---|---|---|---|---|---|---|
| | Stresses applied Direct. | Stresses due to Trains and Sleepers. | Stresses of Top Apices. | Totals. | Stresses applied Direct. | Stresses due to Longitudinals. | Stresses at Top Apices. | Totals. |
| | Tons. | Tons. | Tons. | Tons. | Tons. | Tons. | Tons. | Tons. |
| 0 | 40,768 | 11,050 | ... | 51,818 | 66,962 | 7,425 | ... | 74,387 |
| 1 | 26,908 | 22,100 | ... | 49,008 | 34,506 | 14,850 | ... | 59,356 |
| 2 | 81,534 | 22,100 | 60,182 | 163,816 | 133,926 | 14,850 | 95,583 | 244,359 |
| 3 | 26,908 | 22,100 | ... | 49,008 | 34,506 | 14,850 | ... | 59,356 |
| 4 | 81,534 | 22,100 | 60,182 | 163,816 | 133,926 | 14,850 | 95,583 | 244,359 |
| 5 | 26,908 | 22,100 | ... | 49,008 | 34,506 | 14,850 | ... | 59,356 |
| 6 | 70,473 | 22,100 | 119,278 | 211,851 | 125,506 | 14,850 | 186,978 | 327,334 |
| 7 | 24,557 | 22,100 | ... | 46,657 | 40,666 | 14,850 | ... | 55,516 |
| 8 | 62,118 | 20,188 | 58,752 | 141,058 | 99,810 | 13,220 | 92,359 | 205,389 |
| 9 | 17,816 | 18,275 | ... | 36,091 | 29,713 | 11,610 | ... | 41,323 |
| 10 | 41,331 | 16,329 | 52,569 | 110,229 | 72,130 | 9,936 | 90,432 | 172,498 |
| 11 | 12,723 | 14,382 | ... | 27,105 | 21,250 | 8,262 | ... | 29,512 |
| 12 | 27,622 | 12,614 | 38,203 | 78,439 | 49,393 | 6,872 | 61,656 | 117,921 |
| 13 | 8,887 | 10,846 | ... | 19,733 | 14,426 | 5,481 | ... | 19,907 |
| 14 | 18,595 | 9,350 | 24,428 | 52,373 | 32,171 | 4,523 | 40,702 | 77,396 |
| 15 | 6,091 | 7,854 | ... | 13,945 | 9,628 | 3,564 | ... | 13,192 |
| 16 | 11,298 | 6,650 | 9,125 | 27,073 | 16,002 | 2,997 | 10,290 | 29,289 |
| 17 | 2,898 | 2,678 | ... | 5,576 | 4,712 | 1,215 | ... | 5,927 |
| | ... | ... | ... | 158,347 | ... | ... | ... | 212,682 |

On Sheet 20 the diagrams will be found which serve to deter-

mine the moments of flexion and the strains along the bars of the bracings.

The results of these calculations are embodied in the following tables:—

| Members. | Length of Members. | Case of Bridge Loaded. | | Case of Bridge Free. | |
|---|---|---|---|---|---|
| | | Stresses. | Weights. | Stresses. | Weights. |
| | Metres. | Tons. | Tons. | Tons. | Tons. |
| $A_1$ | 25,000 | 1·508 | 28,916 | 2·665 | 51,101 |
| $A_2$ | 25,000 | 1·608 | 30,833 | 2·720 | 52,156 |
| $B_1$ | 25,000 | 1·884 | 36,126 | 3·020 | 57,909 |
| $B_2$ | 25,000 | 2·188 | 41,955 | 3·380 | 64,812 |
| $C_1$ | 25,000 | 2·680 | 51,389 | 3·980 | 76,317 |
| $C_2$ | 25,000 | 3·200 | 61,395 | 4·660 | 89,356 |
| $D_1$ | 25,029 | 3·200 | 61,395 | 4·660 | 89,459 |
| $D_2$ | 25,029 | 2·687 | 51,583 | 3·915 | 75,157 |
| $E_1$ | 21,525 | 2·152·4 | 35,534 | 3·120 | 51,511 |
| $E_2$ | 21,525 | 1·742·7 | 28,770 | 2·490 | 41,110 |
| $F_1$ | 18,021 | 1·298·4 | 17,946 | 1·855 | 25,640 |
| $F_2$ | 18,021 | 992·6 | 13,720 | 1·365 | 18,867 |
| $G_1$ | 14,517 | 654 | 7,282 | 817 | 9,097 |
| $G_2$ | 14,517 | 406·8 | 4,530 | 518 | 5,768 |
| $H_1$ | 11,013 | 145·6 | 1,230 | 164 | 1,385 |
| $H_2$ | 11,013 | 254·7 | 2,151 | 354 | 2,990 |
| I | 7,509 | 382 | 2,200 | 523 | 3,012 |

| Description of Spans. | Description of Sides including the Inclined Members. | Total Strains on the Two Inclined Members. | Length of each Inclined Member. | Weight of each Inclined Member. |
|---|---|---|---|---|
| | | Tons. | Metres. | Tons. |
| Central span . . . | (0, 1) | 175 | 35,355 | 4,745 |
| | (1, 2) | 495 | 35,355 | 13,423 |
| | (2, 3) | 572 | 35,355 | 5,511 |
| | (3, 4) | 765 | 35,355 | 20,745 |
| | (4, 5) | 842 | 35,355 | 22,833 |
| | (5, 6) | 2,138 | 35,355 | 57,977 |
| | Total for one half span . . . . | | | 135,234 |
| Cantilever arms . . . | (6, 7) | 2·332 | 34,500 | 61,708 |
| | (7, 8) | 1·455 | 33,250 | 37,107 |
| | (8, 9) | 1·262 | 29,350 | 28,410 |
| | (9, 10) | 1·105 | 28,250 | 23,943 |
| | (10, 11) | 998 | 24,150 | 18,486 |
| | (11, 12) | 782 | 23,750 | 14,246 |
| | (12, 13) | 675 | 20,100 | 10,407 |
| | (13, 14) | 548 | 19,300 | 8,112 |
| | (14, 15) | 465 | 16,050 | 5,724 |
| | (15, 16) | 370 | 15,650 | 4,442 |
| | (16, 17) | 309 | 12,600 | 2,987 |
| | Total for one cantilever arm . . . | | | 215,572 |

Aggregate weight of all the bars of the lower bracings :—

| | |
|---|---|
| In a central span of 300 metres . . . . . . . . . | 270,468 |
| In two cantilever arms of 187·5 metres . . . . . . | 431,144 |

INCLINED BRACINGS.—The bracings which connect, twos-and-twos, the struts or compression members of the main girders, must be capable of transmitting to the lower apices those stresses acting on the top apices.

The tensions and the compressions of the bars of these bracings may be determined by simple diagrams, such as are used in statics.

Stresses are also developed in the straits of the main girders.

The following tables give the results :—

| Main Bars of Girders. | Weight. | |
|---|---|---|
| | Bridge Loaded. | Bridge Free. |
| | Tons. | Tons. |
| *a* | 9,170 | 14,600 |
| *b* | 9,170 | 14,600 |
| *d* | 9,170 | 14,600 |
| *f* | 9,170 | 14,600 |
| *g* | 8,294 | 13,000 |
| *i* | 6,969 | 10,900 |
| *k* | 4,686 | 8,100 |
| *m* | 2,217 | 3,580 |
| *o* | 0,746 | 1,250 |
| *q* | 0,311 | 0,350 |

| Corresponding Bars. | Weight of Cross Bracings. |
|---|---|
| | Tons. |
| *a* | 5,698 |
| *b* | 5,698 |
| *d* | 5,698 |
| *f* | 5,698 |
| *g* | 5,377 |
| *i* | 5,717 |
| *k* | 4,897 |
| *m* | 3,807 |
| *o* | 0,335 |
| *q* | 0,370 |
| Total . . . | 43,295 |

Total weight of the inclined bracings :—

| | Tons. |
|---|---|
| In the central span of 300 metres . . . . . . . . | 45,584 |
| In the two cantilever arms of 187·5 metres, each . . . . | 41,006 |

CALCULATION OF EFFECTS DUE TO COUPLES.—The nature of these effects having been indicated above, the results of the calculations will alone be here stated.

| Vertical Strains due to Couples P$h$ and P'$h'$. | | | Weights of Top and Bottom Members necessary to enable them to withstand Couples P'$\lambda$. | | |
|---|---|---|---|---|---|
| Apices Loaded. | Bridge Loaded. | Bridge Free. | Chords. | Bridge Loaded. | Bridge Free. |
| | Tons. | Tons. | | Tons. | Tons. |
| 0 | 4·6 | 2·6 | $A_1$ | 0·956 | 1·911 |
| 1 | 9·2 | 5·3 | $A_2$ | 0·956 | 1·911 |
| 2 | 165·7 | 253·8 | $B_1$ | 2·110 | 3·744 |
| 3 | 9·2 | 5·3 | $B_2$ | 2·110 | 3·744 |
| 4 | 165·7 | 253·8 | $C_1$ | 3·264 | 5·576 |
| 5 | 9·2 | 5·3 | $C_2$ | 3 264 | 5·576 |
| 6 | 306·7 | 471·7 | $D_1$ | 3·264 | 5·601 |
| 7 | 9·4 | 5·4 | $D_2$ | 3·264 | 5·601 |
| 8 | 150·0 | 226·9 | $E_1$ | 1·978 | 3·255 |
| 9 | 9·1 | 4·3 | $E_2$ | 1·978 | 3·255 |
| 10 | 126·6 | 208·7 | $F_1$ | 0·912 | 1·444 |
| 11 | 6·9 | 3·2 | $F_2$ | 0·912 | 1·444 |
| 12 | 81·7 | 124·5 | $G_1$ | 0·141 | 0·485 |
| 13 | 5·6 | 2·2 | $G_2$ | 0·141 | 0·485 |
| 14 | 42·8 | 64·8 | $H_1$ | 0·055 | 0·062 |
| 15 | 4·4 | 1·5 | $H_2$ | 0·055 | 0·062 |
| 16 | 13·3 | 12·0 | I | 0·055 | 0·062 |
| 17 | 1·6 | 0·5 | ... | ... | ... |

4. *The Tension and Compression Members of the Main Girders.*

The same methods of calculation are here adopted as in the case of the independent span. The results are as follows :—

| Corresponding Apices. | Weight of Tension and Compression Members. | Corresponding Apices. | Weight of Tension and Compression Members. |
|---|---|---|---|
| | Tons. | | Tons. |
| 1 | 4,828 | 9 | 3,784 |
| 3 | 5,412 | 11 | 2,134 |
| 5 | 6,593 | 13 | 1,116 |
| 7 | 6,332 | 15 | 0,541 |

5. *Main Girders.*

Each main girder comprises a central span of 300 metres, and the two adjacent overhanging portions of 187,500 metres each.

What has now to be determined is the weight that will enable each girder to resist vertical strains. Such strains are due to a variety of causes:—

To the weight of the plates, rails, &c.

To the weight of the sleepers under the rails.

To the weight of the beams.

To the weight of the bars of the lower bracings.

To the weight of the bars of the inclined bracing.

To the weight of the members and struts, which is necessary to enable them to withstand the effects of the wind.

To the vertical stresses due to the wind.

To the weight of the secondary bars of the girders.

To the effects due to the independent span of 125 metres.

To the additional load due to trains (assumed to be at the rate of 3 tons per metre of girder); and lastly,

To the weight of the girders themselves.

With the assistance of the preceding tables, the strains that can be applied to each main apex of the girder may be readily determined.

Owing to the method of construction of the girder, the weights of the lower members and of the struts of the girder may be regarded as transmitted to the lower apices; the top apices only being loaded with the weight of the top members.

The following table indicates the strains that are known, as applied to the apices of half of a girder:—

| Apices. | Case of Bridge Loaded. | Case of Bridge Free. |
|---|---|---|
| | Tons. | Tons. |
| 0 | 170,234 | 105,037 |
| 2 | 498,214 | 484,020 |
| 4 | 539,346 | 531,195 |
| 6 | 743,027 | 823,004 |
| 8 | 506,144 | 486,451 |
| 10 | 386,766 | 371,655 |
| 12 | 266,622 | 218,074 |
| 14 | 170,439 | 115,351 |
| 16 | 83,908 | 38,026 |
| 17 | 483,187 | 326,760 |

The inspection of this table shows that the case of the bridge being loaded is the most unfavourable one. We will, therefore, take the figures of the second column for the calculations of the girders.

Assuming that the approximate weight of the members of the girder is found by any convenient method, such weight will have to be distributed among the different apices, and by adding it to

the figures of the foregoing table we will obtain a fresh series of loads that may serve as a base for a second approximate estimate of the weight.

By repeating the same process a third approximate figure can be obtained, and the calculation may thus be continued until two consecutive approximations represent as nearly as possible the weight of a semi-girder. The stresses developed in each member of the girder have been represented statically.

The final approximations are shown in the diagrams. The results are as follows:—

| Central Span. | | | | Cantilever Arms. | | | |
|---|---|---|---|---|---|---|---|
| Weight of Members. | | Weight of Struts. | | Weight of Members. | | Weight of Struts. | |
| | Tons. | | Tons. | | Tons. | | Tons. |
| I | 1,633 | *q* | 4,927 | C | 144,321 | *f* | 156,976 |
| H | 9,413 | *p* | 9,485 | B | 107,987 | *e* | 122,537 |
| G | 22,558 | *o* | 6,421 | A | 92,442 | *d* | 65,780 |
| F | 43,679 | *n* | 14,706 | C′ | 121,117 | *c* | 59,267 |
| E | 79,477 | *m* | 12,121 | B′ | 96,293 | *b* | 19,488 |
| D | 145.143 | *l* | 28,261 | A′ | 45,088 | *a* | 13,669 |
| I′ | 4,528 | *k* | 26,070 | | | | |
| H′ | 16,320 | *j* | 56,578 | | | | |
| G′ | 33,340 | *i* | 57,525 | | | | |
| F′ | 59,976 | *h* | 108,914 | | | | |
| E′ | 106,670 | *g* | 117,233 | | | | |
| D′ | 172,280 | | | | | | |

These are the weights necessary to resist vertical strains.

To determine the real weights, the stresses due to the action of wind should be added.

Thus the total weights of the two main girders are as follows:—

In one central span of 300 metres . . . . . 5,379·684 tons.
For the two cantilever arms of 187·5 metres each . . 5,594·104 „

The diagrams on Sheet 19 * show that owing to the incline of the girders the compression stresses are developed in the lower bars of the struts; it has been ascertained that they are capable of sustaining these stresses.

## § 3. Metal Columns.

In determining the stability of the metal columns the following two cases have been considered:—

* These diagrams have not been reproduced in the *Journal.*—Ed.

1. When the wind acts horizontally and at right angles to the longitudinal axis of the bridge, or transversely to the bridge; and

2. When the wind acts horizontally, and in the direction of the longitudinal axis of the bridge.

In these two cases the thrust at the head of the columns due to expansion is added to the effects of the wind.

In the first case, the surfaces exposed to the wind are, with regard to the superstructure, those which have been determined by the calculations of the bracings of the main girders; and in regard to the metal columns, they represent the sum of the diametrical surfaces of the piers, which are considered as invariable throughout their height.

In the second case, the vertical projections of the members of the girders of the lower and upper bracings (supposed to be flat for a distance equal to the heights of the sums of the girder braces) and the sum of the vertical projections of all the remaining bars, beams, &c., have been taken into account in dealing with the superstructure.

Considering that all these members are comparatively close to each other, it is amply sufficient to take half of the total surfaces. In the case of the metal column the sum of the superficial diameters of the two piers and of the five rows of pier bracings has been taken.

The wind pressures are the same as those assumed in the calculations of the floor, that is to say, 270 kilogrammes per square metre in the case of the superstructure being free from any load, and 170 kilogrammes when the superstructure is loaded by trains.

| | Wind. | | |
|---|---|---|---|
| | Transverse. | | Longitudinal. |
| | Floor Free. | Floor Loaded. | Floor Free. |
| Stress of wind pressure upon 400 metres of superstructure effecting a metal pier . . . . . . . | 2·050T | 1·455T | 767T |
| Height of the centre of pressure above the axis of the lower member . . | 20m,1 | 19m,4 | 24m,3 |
| Weight of 400 metres of superstructure effecting the metal column . | 7·162T | 7·162T | 7·162T |
| Inner framings of the lower members on the right of the supports . . | 30T | 30T | 30T |
| Overcharge of 6 tons per running metre of bridge . . . . . . | ... | 2·400T | ... |
| Total . . | 7·192T | 9·592T | 7·192T |
| Weight acting on one pillar . . | 3·596T | 4·796T | 3·596T |

## 1. *Stability under the Action of Transverse Wind.*

Bed Plates.—The greatest load supported by a bed plate is that which results at the time when the bridge is subjected to additional load.

The distance between the base of a bed plate and the axis of the lower member is 1·4 metres.

The load is expressed by the following formula:—

$$C = P + \frac{M}{\delta}$$

Load due to the superstructure . . . 4·796 tons.
Load due to the bed plate and accessories . 6 tons.

$$P = 4802 \text{ tons.}$$

M, being the moment of overturn under the action of the wind, is equal to 1·455 tons × (19·4m. × 1·4m.) = 30·26 tons.

$\delta$, being the distance of the columns, equals 25 metres.

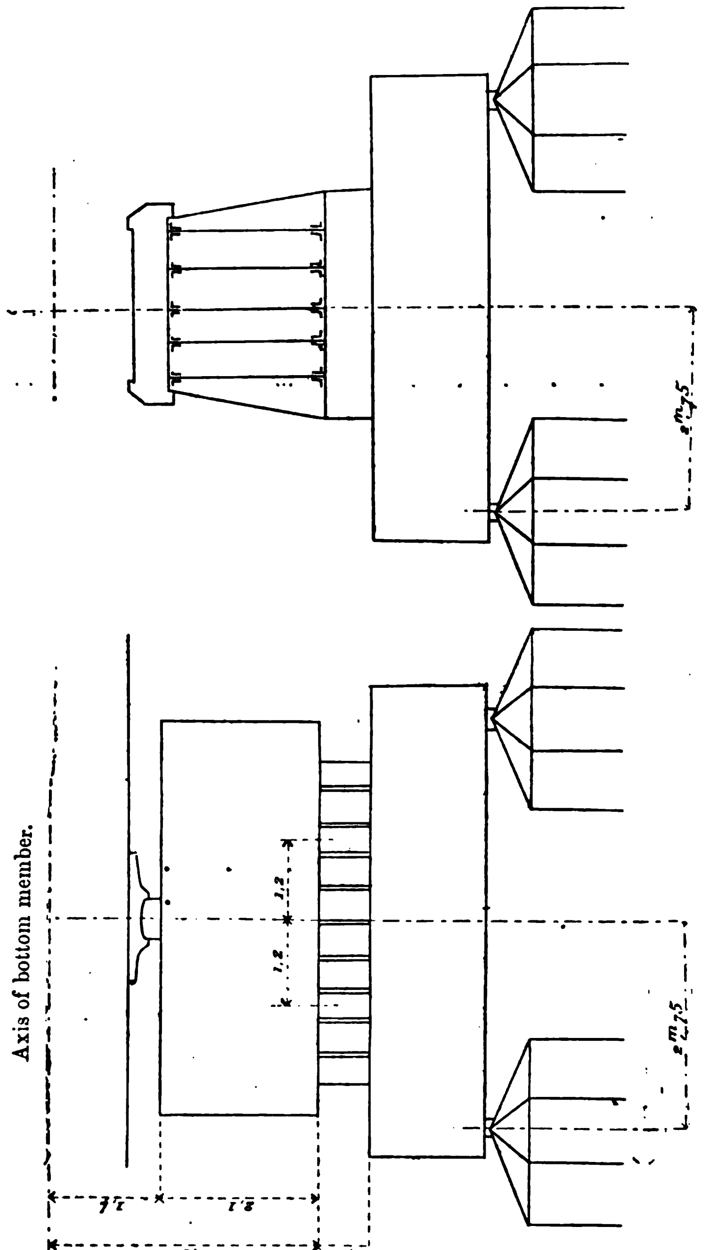
$$C = 6{,}012{\cdot}6 \text{ tons.}$$

The surface of support for the bed plate is 2m. = ·5m. = $1m^2$.

The crushing stress is equal to—

$$R = 6\text{K per square millimetre.}$$

STABILITY ABOVE THE ROLLERS.



| Particulars. | | Bridge Free. | Bridge Loaded. |
|---|---|---|---|
| Wind on floor | $v$ | 2·050T | 1·455T |
| Height of centre of pressure | $g$ | 23m,6 | 22m,9 |
| Moment of overturn | $vg=m$ | 48·380TM | 33·320TM |
| Wind on expansion slides | $v'$ | 6T | 3T,8 |
| Height of centre of pressure | $g'$ | 1m,05 | 1m,05 |
| Moment of overturn | $v'g'=m'$ | 6TM | 4TM |
| Total moment of overturn | $m+m'=M_r$ | 48·386TM | 33·324TM |
| Total pressure of wind | $v+v'=V$ | 2·056T | 1·458T,8 |
| Weight of floor | $p$ | 7·192T | 9·592T |
| Weight of pieces above rollers | $p'$ | 134T | 134T |
| Total weight | $p+p'=P$ | 7·326T | 9·726T |
| A half distance between columns | $\frac{1}{2}\delta$ | 12m,5 | 12m,5 |
| Moment of stability | $P\delta=M_s$ | 91·575TM | 121·575TM |
| Coefficient of safety | $\frac{M_s}{M_r}$ | 1,89 | 3,65 |
| Relation of stress of wind to the weight | $\frac{V}{P}$ | 0,28 | 0,15 |

Expansion Slides.—The slide which is to support the heaviest load is situated under the girder exposed to the wind when the bridge is loaded. It is subject to the action of the rollers, which is equal to—

$$P \times \frac{M}{\delta}$$

P, being the load supported by the column $=\frac{9{,}726}{2}=4{,}863$ tons.

M, being the moment of overturn = 33,324TM.

$\delta$, being the distance between the columns = 25m.

The effect above the rollers equals 6,196 tons.

Supposing that all the rollers support the same load, the centre effect on either side the axis of the socket is at a distance of 1m·2 metres, and the moment of deflexion at the centre of the slide is equal to—

$$\frac{6{,}196\text{T}}{2} \times 1\text{m}{\cdot}2 = 3717\text{TM}{\cdot}6$$

The section of the slide is a value of $\frac{I}{n}=323{,}610$.

The maximum strain per square millimetre of section is equal to 11K·48.

Rollers.—The greatest weight that the rollers under the

expansion slides is required to resist equals 6196 tons. The weight of ten rollers together is 45 tons. Each roller supports at its base a load of

$$\frac{6196 + 45}{10} = 624{\cdot}1 \text{ tons.}$$

The strain per unit of surface, according to M. Contamin, is—

$$R^3 = \frac{9}{64} \frac{EQ^2}{l^2 r^2}$$

R being the stress to be determined.
E the modulus of elasticity $= 22{\cdot}5 \times 10^9$.
Q weight of a roller = 624,100.
$l$ length of a roller = 3m.
$r$ radius of a roller.

$$R = 11{\cdot}51\text{K per } {}^{m}/_{m}{}^{2}$$

The thrust whereby the rollers are set in motion, which will be considered farther on, is equal to—

$$F = \frac{a}{2r} Q \text{ for each roller.}$$

$a$ being the width of the deformed portion that has undergone expansion.

$$\frac{a}{2r} = \frac{1}{2} \sqrt[3]{\frac{24Q}{Elr}} = 0{,}000{,}529 \sqrt[2]{Q}$$

Circular Roller Supports.—The supports rest upon columns by means of a circular support 2·75 metres in radius. They are formed of two circular plates of 60 millimetres thickness, the inner distance between them being 1·28 metres. They are strengthened by ribs and crowns of sheet-iron, and by angle irons. The total pressure sustained by the rollers is 6241 tons. The rectangle formed by the end rollers has a surface of—

$$4{\cdot}2\text{m} \times 3\text{m} = 12{\cdot}2\text{m} \cdot 6.$$

The pressure per square metre is equal to—

$$\frac{6241}{12{\cdot}6} = 496 \text{ tons.}$$

Supposing that the load is the same throughout the surface of the plate, the maximum stress, according to the formula of MM. Lévy, would be—

$$R = p \frac{a}{h^2 - h_1^2}$$

$p$ being the pressure per square metre = 496,000 kilos.
$a$ being the radius of support = 2·75m.
$h$ being the external height = 1·40m.
$h$ being the internal height = 1·28m.

$$R = 11{\cdot}7\text{K per } {}^{m}/_{m}{}^{2}.$$

PIER BRACINGS.—The bracings that connect the piers are five in number, and are arranged parallel to each other. They sustain the greatest strains when the bridge is free, assuming that the wind has an intensity of 250 kilogrammes per square metre.

The system of bracings being double, the pressures are supposed to be equally divided between the two halves, one half of the pressure being sustained by the points of attachment to the windward piers, and the other half by those of the leeward piers. The section of the bars forming the bracings will enable them to bear a strain of 12 kilogrammes per square millimetre.

METAL PIERS.—The piers carry the aggregate weight of all the metal parts, and they resist, at the same time, the action of transverse wind and the flexure produced by a stress capable of setting into motion the expansion rollers.

For any pier section we must have—

$$R = \frac{P}{S} + \frac{P'}{S} + \frac{p}{S} + \frac{Mn}{Sr^2}$$

- R being the strain per unit of section = 12 kilogrammes per square millimetre.
- P the weight of all the known metal parts acting above the section under consideration.
- P′ the stress on portion of pier, due to wind, through the medium of the bracing.
- $p$ weight of the part of pier, which is here unknown.
- M the moment due to thrust caused by expansion.
- $n$ distance of the remotest web from the centre of gravity of the section.
- $r^2$ is the square of the radius of the gyration of the section under consideration.
- S the section of the component, the value of which is—

$$S = \frac{p}{1{,}18\,\pi\,l}$$

The co-efficient 1·18 is the allowance made for the fittings and rivetings.

$\pi$ being the specific gravity of the steel = 7·8.

$l$ being the length of the segment of pier under consideration.

These two expressions will give—

$$p = \frac{\dfrac{P + P + \dfrac{Mn}{r^2}}{R}}{1{,}18\,\pi\,l} - 1$$

Thus it is this formula which serves to determine the weight of the segments of the pier. The load is less than that indicated in the case of a longitudinal action of the wind, and it is only mentioned here in passing.

STABILITY AT THE BASE OF THE PIERS.—The conditions of stability under the action of transverse wind are indicated in the following table:—

| Particulars. | | Bridge Free. | Bridge Loaded. |
|---|---|---|---|
| Wind on superstructure | $v$ | 2·050T | 1·455T |
| Height of centre of pressure | $g$ | 61m,1 | 68m,4 |
| Moment of overturn | $vg=m$ | 125·255Tm | 87·882Tm |
| Wind upon expansion slides | $v'$ | 6T | 3T,8 |
| Height of centre of pressure | $g'$ | 38m,55 | 38m,55 |
| Moment of overturn | $v'\,g'=m'$ | 231Tm,3 | 146Tm,5 |
| Wind on piers | $v''$ | 162T | 102T |
| Height of centre of pressure | $g''$ | 18m,75 | 18m,75 |
| Moment of overturn | $v''\,g''=m''$ | 3·037Tm,5 | 1·912Tm,5 |
| Total moment of overturn | $m+m'+m''=M$ | 128·523Tm,8 | 89·941Tm |
| Total stress of wind at base | $v+v'+v''=V$ | 2·218T | 1·560T,8 |
| Weight of metal flooring | $p$ | 7·192T | 9,592T |
| Weight of supporting apparatus and metal columns | $p'$ | 1·982T | 1·982T |
| Total weight | $p+p'=P$ | 9·174T | 11·574T |
| Half distance between the piers | $\frac{1}{2}\delta$ | 12m,5 | 12m,5 |
| Moment of stability | $M_r$ | 114·675Tm | 144·675Tm |
| Ratio of moments | $\frac{M_r}{M_r}$ | 0,89 | 1,6 |
| Relation of the stress of the wind to the load | $\frac{V}{P}$ | 0,24 | 0,13 |

SUBSTRUCTURE OF PIERS.—The substructure of the piers produces maximum pressures on the masonry in the case of wind

acting longitudinally. The calculations in this connection are reproduced farther on.

ANCHOR TUBES.—When the bridge is not loaded, the stability at the base of the piers can only be ensured by means of anchorings or holding-down bolts.

The pull on these pieces is represented by this formula.

$$T = \frac{M}{\delta} - P.$$

M being the moment of overturn at the base of the piers = 25m.

$\delta$ the distance between the piers $= \frac{9{\cdot}74}{2} = 4{\cdot}587$T.

P the weight acting on the base of the piers = T = 554.

The section of the centre tube alone is ·3237 square metres.

The strain at the anchorings, therefore, is insignificant.

ANCHOR BOLTS.—By the effect of expansion the tubes are caused to oppose little resistance to the overturning strain, being situated in the centre of the piers, but here the anchoring bolts have to be considered. They have a maximum stress to sustain in the case of longitudinal wind. We will refer to them farther on.

STABILITY OF THE MASONRY AT THE LEVEL OF THE TIE-BANDS. —The height of the masonry that is subject to the effects of anchoring must be such as to prevent lifting.

The maximum and minimum pressures may be represented by this formula—

$$C = \frac{P+p}{S} \pm \frac{Mn}{I}.$$

The quantities expressed in this formula are indicated in the following table:—

| | | |
|---|---|---|
| Weight of metal parts | $P$ | 9·174T |
| Height of anchoring | $h$ | 14m |
| Surface at the top of the masonry | $S$ | 625m²,8 |
| Weight of masonry without the sloping portion | $p$ | 21·028T |
| Total weight at level of tie-bands | $P+p$ | 30·202T |
| Moment of overturn at level of substructures | $m$ | 128·523Tm,8 |
| Stress of wind at level of substructures | $v$ | 2·218T |
| Moment of overturn | $vh=m'$ | 31·052Tm |
| Stress of wind upon masonry | $v'$ | 64T,4 |
| Moment of overturn | $v' \times \frac{1}{2}h = m''$ | 450Tm,8 |
| Total moment of overturn | $m+m'+m''=M$ | 160·026Tm,6 |
| Value of $n$ | $n$ | 21m |
| Value of I | $I$ | 77·991,6 |
| Pressure upon masonry on the windward side | $C$ | 0k,5 par c.m.² |
| Pressure upon masonry on the leeward side | $C$ | 9k, 1 par c.m.² |
| Total pressure of wind | $v+v'=V$ | 2·282T,4 |
| Relation of wind to the load | $\frac{V}{P+p}$ | 0,075 |

The expansion which tends to overturn the column in the direction of the length of the bridge does not to an appreciable extent alter the results indicated above.

### 2. *Stability under the Action of Longitudinal Wind.*

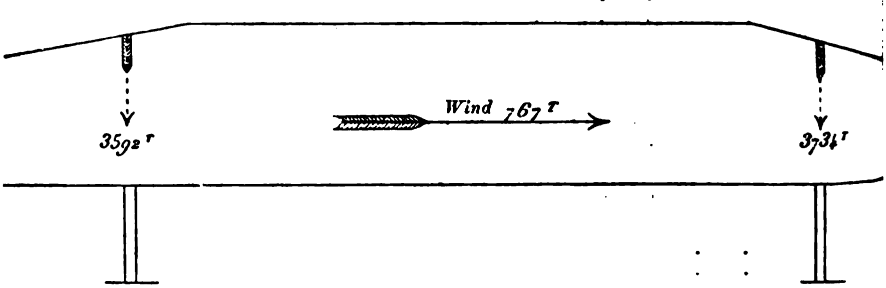
When the action of wind is longitudinal, the thrust felt at the head of the piers joins the strain due to expansion. The piers which support the rollers cannot exercise a resistance more powerful than is the strain which is capable of setting such rollers in motion. The consequence is that the difference is transmitted to the piers with fixed supports, those without expansion rollers. The greatest overturning strain further acts upon the piers on the leeward, without expansion rollers, when the bridge is not loaded.

The vertical strain that acts above the rollers is equal to $P \pm \frac{M}{a}$.

The values of this formula are indicated in the following table:—

| | | |
|---|---|---|
| Weight of metal parts on pier | P | 3·663T |
| Pressure of wind upon 800 metres of girder | V | 767T |
| Height of centre of pressure above the rollers | H | 27m,8 |
| Moment of overturn | VH = M | 21·322Tm,6 |
| Distance of piers | $d$ | 300m |
| Vertical stress upon rollers (windward piers) | ... | 3·592T |
| Vertical stress upon leeward piers | ... | 3·734T |
| Load upon one roller $\frac{3{\cdot}592T + 45T}{10}$ | Q | 363·700k |
| Co-efficient of rolling friction according to the formula found before, namely, $0{,}000{\cdot}529 \sqrt[3]{Q} =$ | K | 0,038 |
| Strain required to set the rollers in motion | 3·637T × 0,038 | 138T,2 |

### METHOD OF DETERMINING THE STRAINS AT THE HEAD OF THE PILLARS ABOVE THE LEVEL OF THE ROLLERS.




With rollers. Without rollers

| | | | | |
|---|---|---|---|---|
| → | 138T,2 . . . | Contraction . . . | 138T,2 | ← |
| → | 0 . . . | Wind . . . . | 67T | → |
| → | 138T,2 . . . | Resultant . . . | 628T,8 | → |

Thus the pillars at their heads have to sustain a maximum strain of 628T.8.

METAL PIERS.—The piers support the weight of all the metal parts, and at the same time resist the action of longitudinal wind and the flexure produced by the horizontal stress at the heads, which is 628T.8, being due to the combined effects of the wind and the expansion of the superstructure.

Taking any desired section of the pier, we must have

$$R = \frac{P}{S} + \frac{p}{S} + \frac{n}{Sr^2}(M + m + m')$$

R being the strain sustained by the metal per unit of section = 12 kilogrammes per square millimetre.

P weight of the known metallic parts.

$p$ weight of part of the pier under consideration (the value of this has to be determined).

M moment due to the horizontal stress at the head of the pier.

$m$ moment due to the stress of wind acting upon the bracings, such stress being centred upon each apex.

$m'$ moment of force of the wind upon the pier.

$n$ distance of web farthest from the centre of gravity of the section.

$r^2$ the section of the radius of gyration of the section under consideration.

S′ section of part of pier of a value of

$$S = \frac{p}{1.18\pi l.}$$

1·18 being the co-efficient which makes allowance for the fittings and rivetings.

$\pi$ specific gravity of steel = 7·8.

$l$ length of the pier segment under consideration.

From these two expressions the following formula results:—

$$p = \frac{P + \frac{n}{r^2}(M + m + m')}{\frac{R}{1 \cdot 18 \pi l} - 1}$$

The weight of each of the parts of the pier has been determined with the assistance of this formula. The minimum thickness of 10 millimetres has been maintained with regard to all the samples of steel of which the sections are composed.

STABILITY AT BASE OF PIERS.—The stability at the base of a pier cannot be given unless by taking into account the anchor bolts. The foundation-plate in contact with the masonry presents a circular surface with portions cut out.

The maximum pressures transmitted by this plate to the masonry are expressed by the following formula:—

$$C = \frac{P}{S} \pm \frac{Mn}{Sr^2},$$

the values of which appear in the following table:—

| | | |
|---|---|---|
| Vertical load above rollers | $p$ | 3·734T |
| Weight of the parts of the pier situated above the upper level of the rollers | $p'$ | 924T |
| Total vertical load upon superstructure of pier | $p+p'=P$ | 4·658T |
| Surface of foundation-plate | S | 69m²,68 |
| Crushing strain on masonry per square centimetre | $\frac{P}{S}$ | 6k,7 |
| Horizontal stress on head of pier | F | 628T,8 |
| Height of centre of action above the substructure | H | 37m,5 |
| Moment of overturn | $FH=m$ | 23·580Tm |
| Wind upon bracings | $v$ | 74T,6 |
| Height of centre of pressure | $h$ | 17m,8 |
| Moment of overturn | $vh=m'$ | 1·327Tm,9 |
| Wind on pier | $v'$ | 82T,5 |
| Height of centre of pressure | $h'$ | 18m,75 |
| Moment of overturn | $v'h'=m''$ | 1·546Tm,9 |
| Total moment of overturn | $m+m'+m''=M$ | 26·454Tm,8 |
| External radius of the foundation-plate | $n$ | 6m,2 |
| Square of the radius of gyration | $r^2$ | 10,97 |
| Effect on masonry from flexure per square centimetre | $\frac{Mn}{Sr^2}$ | ±21k,5 |
| Maximum compression on the leeward side per square centimetre | C | 28k,2 |
| Maximum compression on the windward side per square centimetre | C | −14k,8 |
| Horizontal stress at level of substructure | $F+v+v'$ | 785T,9 |
| Relation of horizontal stress to vertical load | $\frac{F+v+v'}{P}$ | 0,17 |

The anchor bolts or holding-down bolts oppose the overturning tendency. Their maximum tension is assumed to be—

$$t=\frac{1}{S}\left(\frac{Mn}{r^2}-P\right).$$

The values of this formula are as follow:—

| | | |
|---|---|---|
| Diameter of bolt . . . . . . . . | | 0m ,25 |
| Sum of sections of 12 bolts . . . . . . | | 0m²,589 |
| Moment of overturn . . . . . . . . | | 26.454Tm,8 |
| Radius of circle of bolts, virtual value . . . | $n$ | 5m ,55 |
| Square of radius of gyration . . . . | $r^2$ | 15 ,4 |
| Vertical loads . . . . . . . . | P | 4.658T |
| Maximum tension per square millimetre . . | $t$ | 8k ,26 |

Stability at Base of Anchor Bolts.—The maximum and minimum loads on the masonry at the level of the tie-bands is expressed in the following formula:—

$$C=\frac{P+p}{S}\pm\frac{Mn}{I},$$

the different values of which are indicated in the following table:—

| | | |
|---|---|---|
| Weight of metal parts for two piers . . . | P | 9·316T |
| Height of anchorings . . . . . . . | $h$ | 14m |
| Surface of masonry at top . . . . . . | S | 625m²,8 |
| Weight of masonry without the sloping portion . | $p$ | 21·028T |
| Total weight at level of tie-bands . . . | $P+p$ | 30·344T |
| Moment of overturn at level of substructures of the two piers . . . . . . . . | $m$ | 52·909Tm,6 |
| Horizontal stress at level of substructures . . | F | 1·571T ,8 |
| Moment of overturn . . . . . . . | $Fh=m'$ | 22·005Tm,2 |
| Stress of wind upon masonry . . . . . | $=v$ | 158T ,8 |
| Moment of overturn . . . . . . . | $v\times\frac{1}{2}h=m''$ | 1·111Tm,6 |
| Total moment of overturn . . . . . . | $m+m'+m''=M$ | 76·026Tm,4 |
| Value $\frac{I}{n}$ of the surface of the masonry . . | $\frac{I}{n}$ | 1·683 : ,6 |
| Crushing stress per square centimetre . . | $\frac{P+p}{S}$ | 4k ,8 |
| Maximum flexure per square centimetre . . | $\frac{Mn}{I}$ | 14k ,5 |
| Minimum pressure on windward masonry per square centimetre . . . . . . | C | 0k ,3 |
| Maximum pressure on leeward masonry per square centimetre . . . . . . . . | C | 9k ,3 |
| Horizontal stress at level of tie-bands . . . | $F+v$ | 1·730T ,6 |
| Relation of horizontal strains to load . . . | $\frac{F+v}{P+p}$ | 0 ,057 |

## *DISCUSSION.*

The PRESIDENT said that, before asking any one to open the discussion, he thought he ought to say that it was desirable that members should confine themselves, in the consideration of the paper, to the question as it affected the use of iron and steel, and also as to its mechanical construction. The political questions and the questions of navigation which arose were not subjects that the Institute would consider itself competent to treat. He would, therefore, ask members, in discussing the paper, to confine themselves to the points affecting them as members of the Iron and Steel Institute, and as mechanical engineers. It would be very appropriate if the discussion was opened by their past-President, Mr. Daniel Adamson, who was competent to deal with many of the questions raised in the paper.

Mr. DANIEL ADAMSON said he should be very glad to follow the lines that the President had shadowed forth, but he had an impression that it would be impossible to look at this great international subject without considering its ultimate value, and whether they or the French nation might not be giving twenty-five shillings for a sovereign. The probabilities of carrying out this proposed project depended, of course, on commercial considerations; and in competition with it, they had also before them, that which had repeatedly been made known, both in France and in other countries of Europe, the prospective construction of a tunnel, and a tunnel through ground that was exceedingly favourable for such an undertaking. They could not hide from themselves the fact that any superstructure carried across such a channel must largely interfere with the free pathway of nations, which had a right to run steamers in every direction at will without interruption. They were also bound to look at what would be the real and prospective position of international competition ten years hence, when this great structure would be likely to be completed, if the money was ever found to commence it with. It was more

than probable that steamships would, in the interval, have established a greatly increased economy—that any future ten years might do as much to extend their cheap carrying power as any past ten years had done, and they knew that that period had taken off one-half the quantity of fuel required to carry a given weight across the ocean. Seeing that a steamship could carry at one-fiftieth of a penny per ton per mile, and that a good railway wanted from 1d. to 2½d. per ton per mile, the present work did not look very encouraging, merely looking at it commercially. He did not know whether this development was the outcome of a vigorous and youthful brain, whose courage was only equalled by its audacity, or whether it was the matured thought of practical, experienced men like themselves—men in mature life, who wished to look at the matter all round, and to view the subject in a very careful and considerate manner. They had certainly the advantage of a structure in their own country—the Forth Bridge—which showed that openings of 1700 feet could be practically spanned. The largest span in the proposal before them was about 1640 feet, so that the cantilever system could be carried out, no doubt, equally well in the Channel, and probably it was the only principle upon which a great structure of the sort could be erected. Thanks to their Institute, the material selected for the Forth Bridge had been produced of the required quality, and it had been found a very safe and suitable medium for carrying out large spans, such as were shadowed forth in this great international undertaking. He saw with some degree of pleasure that the girders and the structural arrangement selected had not been that of the Forth Bridge. The main upper and lower members of the Forth Bridge were constructed with a circular hollow section or elliptical form, and longitudinally in a curved line, and he could imagine nothing more costly, tedious, or harassing to the mechanical engineer than a curved elliptical suspension or compressed member for a large bridge. In the present scheme, a truss girder had been adopted. Wind would have much less influence on such a structure; but whether it would require a smaller army of painters to keep and preserve it he was not prepared to say. No doubt, in a great work of that sort, to maintain it, and keep it coated with paint, would entail an enormous annual cost. So far as the girders and the upper

structure were concerned, he thought they might rest assured that there would be no risk of failure. If there was failure at all, it must be in the piers or the foundations, subject as they would be to the action of the waves, and resting in a position where, perhaps, it would be somewhat difficult for human energy to make them secure in every case. Presuming, however, that the structure was finished, and all made secure, he thought it would be more liable to accident than any other means of getting across the Channel. A single collision, knocking a piece of the structure into disorder, would be very likely to stop operations, and the traffic on the bridge, for six or twelve months afterwards, a circumstance very undesirable for those who might have the courage to put their money into such a work. The importance of this subject demanded serious consideration from an international point of view, and he was not one to blame the authors for bringing it forward. In the olden times, there had been as much said against new developments as could be said to-day, and railways in their infancy met with even greater opposition than this bridge had encountered at present. Seeing, therefore, the ultimate advantages that the authors might suggest, he (Mr. Adamson) was bound to confess that he, for one, would never say a harsh word against an enterprise which had for its foundation the commercial development of nations, and the increase of the peace and comfort of all peoples. Under all the circumstances, they were bound to give a hopeful and encouraging expression to those who were deeply and directly interested in such a great national and international work as had been submitted to them that morning, and he agreed with the President that it was a great honour that this paper should have been offered for the consideration of the members of the Iron and Steel Institute.

Mr. Tylden-Wright said he should not like the discussion to close without a warm expression of thanks to the authors on the part of one who had taken a considerable interest in the question of the Channel Tunnel. Those who had believed in that enterprise, and done what they could to support it during the last six or seven years, were very much pleased that there was another scheme now prepared to help them in pushing and

ventilating the question, in the form of a bridge. No doubt great objection had been made to the tunnel, but he felt sure, with Mr. Adamson, that, for the benefit of France and England, the connection must, and would be, made within the next twenty years. As to the practical question, he knew that the gault at the bottom of the Channel was the most suitable for the construction of the tunnel, but he could not say that it was the same for the enormous pillars of the proposed bridge. The cost of the tunnel would not be more than one-sixth of the estimate for the bridge; be believed, therefore, that the vote of commercial men would be in favour of the tunnel, even when the bridge had the sanction and support of such competent and able engineers as M. Schneider, Sir John Fowler, and Mr. Baker.

The President, in proposing a vote of thanks to the authors of the paper, said he thought Mr. Adamson had overlooked the names that guaranteed the proposed bridge. He had said that he did not know whether the design was the outcome of youthful audacity or not; but he would probably give Sir John Fowler credit for having sown his wild oats, and would scarcely accuse him of being extremely youthful. Sir John Fowler and Mr. Baker, in the face of much opposition, had succeeded in completing the Forth Bridge, and in erecting, under considerable difficulties, two spans one-third of a mile each. When they were inspecting the bridge the other day, Sir John Fowler had told him that he would guarantee to construct a bridge across the Channel. There was, therefore, only one formality to be observed, now that the matter was in the hands of such an engineer, namely, that rich nations like England and France should provide the necessary funds. But the matter had even gone a little further, for an eminent financial establishment at Paris was prepared to finance the undertaking. As an iron and steel manufacturer, therefore, he looked upon the project with considerable affection, trusting that a large share of the contracts for the material required would fall into the hands of members of the Institute. The project had been seriously studied, and ably put before the world. The mechanical and scientific calculations had been checked by the first authorities of the day. The political question and the question of navigation appeared to stand

in the way, but with that matter they had nothing to do. They were all, however, deeply indebted to MM. Schneider and Hersent for having made the Institute the medium of placing this imposing project before the public. He proposed a vote of thanks to these gentlemen.

A vote of thanks was thereupon passed to MM. Schneider and Hersent by acclamation.

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## Correspondence.

Mr. Benjamin Baker has remarked that, as on many occasions during the present century the question of a Channel Bridge had been raised and discussed, and the wildest guesses made respecting the cost of such a structure, he thought every one would agree that MM. Schneider and Hersent had done good service in going into the subject in so thorough a manner, and settling once and for all what the actual cost of a Channel Bridge would really be. He certainly did not begrudge the time he had spent in conferring with MM. Schneider and Hersent as to the details of the design, and in making independent estimates of the cost. To show the advisability of such an investigation, he need only recall the fact that twenty-one years ago the late Emperor of the French inspected models, granted interviews to prómoters, and otherwise gave apparently serious consideration to a project for a Channel Bridge, having spans of 3000 metres, or nearly 10,000 feet, an estimated weight of but 250,000 tons of iron, and an estimated cost of but £8,000,000. The 500 metres spans of MM. Schneider and Hersent, the 1,000,000 tons of steel, and the £34,400,000 expenditure represent the difference between serious investigation and wild guessing. On technical points, the paper was so lucid and detailed that no further observations were called for from himself; and as regards practical details, the reputation of the designers of the bridge was so world-renowned as to need no endorsement from any quarter. On questions of navigation and finance he did not claim to be an authority, and he therefore offered no opinion. Very eminent authorities held contrary views on these, as on other questions. The piers undoubtedly would occupy a certain space in the Channel, like so many ships; but, as some naval authorities had pointed out, the

piers would be stationary, whilst with vessels in foggy weather the great difficulty is to know where the other ship is steering. A tunnel would be free from navigation objections, but in other respects, in the opinions of many, the bridge would have the advantage. The earnings of the bridge would clearly be greater than those of a tunnel, for whilst a run across the bridge would constitute a most popular and exhilarating excursion, the passage through thirty miles of tunnel could only be regarded as a disagreeable necessity. Working expenses would be less with the bridge, on account of the heavy charges for ventilating the tunnel. As regards the true relative costs of the two undertakings, all depended upon the view taken of the military question. If the Duke of Cambridge, Lord Wolseley, Sir Lintorn Simmons, and other military authorities who gave evidence before the Select Committee on the Channel Tunnel, were correct in assuming that, in the event of the tunnel being constructed, a permanent addition of about 8000 men to the Dover garrison would be necessary, the capitalised annual charge for the same, added to the £2,000,000 estimated expenditure on fortifications, would amount to a sum of about £24,000,000. If to this sum be added the probable cost of the tunnel, and the capitalised cost of working the ventilating machinery, the £34,000,000 estimate for the bridge, enormous though it may appear at first glance, would in effect be incidental also to the construction of a tunnel. It must not be forgotten either that owing to unexpected fissures the tunnel might prove to be impracticable, even after 90 per cent. of the work had been executed. Probably the most nervous would hardly contend that a bridge which could be disabled by a single gun, afloat or ashore, or by a couple of Fenians with a packet of dynamite, would prove a source of national danger. But, as previously observed, he had given no consideration to any of these questions, nor to the wider question of whether direct railway communication with the Continent was desirable at all, though he had taken much interest in the designs and calculations so ably brought before the Institute by the distinguished authors of the paper under discussion.

Mr. Ewing Matheson observes that the very complete statement and calculations furnished by the designers of the proposed bridge, and the frankness with which they are presented for

criticism, call alike for the admiration and thanks of the Institute. Leaving entirely on one side, as suggested by the President, the political aspect of the case and the expediency of bridging the Straits, there were several points which suggest further inquiry and discussion. The preliminary conditions of headway and length of spans seem to be appropriate. As in the case of all bridges of more than one span, the conflicting advantages of short spans and few piers had been well resolved, for though undoubtedly the maximum span of 500 metres proposed was not the greatest that modern steel allows—for Lindenthal's bridge over New York harbour was to be 2850 feet, and was feasible—yet the great increase in weight per lineal foot of such spans over those proposed for the Channel bridge and the greater difficulties of erection were well avoided, even by the additional supports rendered necessary. The moving load of one ton per lineal foot of each line of railway was ample, considering that the maximum train on each line on any one span would have only two engines. But the question at once arises, Why not have four lines of way? No doubt two would carry the traffic, for there would be no impediments from stations and stoppages. The mere shunting of slow goods trains out of the way of express trains would be easily effected by one or two more "pass-byes," involving an extra width of one or two spans only. But in the case of accidents to a train, blocking one, or perhaps two, lines, the delay would be serious, as the removal of wreckage would be slower and more difficult than on an ordinary railway. It would be interesting to hear from the designers the extra cost of doubling the number of lines. It would certainly not be in proportion to the greater width, for the structure, as designed, was wider than was necessary for the two lines of rails in order to ensure stability against the wind.

The area of bearing surface in the foundations involves an unusually heavy load per square foot, even assuming that all of the area be made effective by the system of construction and anchorage proposed; but taking into account the rare occurrence of the maximum arising from extraordinary wind pressure, the load is not so much greater than in some existing bridges as to be dangerous if the strata proves as hard as the trial borings have indicated. In the sinking of the caissons and building the foundations, the designers appeared to have ventured on the very utmost depth possible for working by compressed air, for

experience at 35 metres was not entirely satisfactory. But modern systems of excavation, as, for instance, at the Gorai River Bridge, India, by Sir B. Leslie, and more recently at the Hawksbury Bridge, N.S.W., showed that greater depths can be dealt with by machinery from above, without the use of compressed air, if neither big boulders nor other obstacles are likely to occur in the strata to be pierced. The worst would be if the piers came foul of a sunken iron steamer; and even then, no doubt, dynamite could be applied at a depth beyond the reach of divers.

While on this point, it was interesting to compare the difficulties of excavation with those in the proposed tunnel scheme. In the latter, from the experience gained in the headings already made at Dover, and from trial borings elsewhere, the promoters do not expect to encounter the sea water. Any land water met with could be dealt with by pneumatic caissons or shields; but if the sea water entered through any fissures in the chalk or other stratum, it would have the pressure due to the head of water above—a pressure too great in the deepest part of the tunnel to allow men to work in compressed air. Any substitute for the ordinary pneumatic plan which might then be proposed would almost certainly be more difficult of execution than in a vertical shaft for the bridge piers.

In regard to the form of superstructure, there could be little doubt, from the reputation of the designers, and that of the English engineers who had reviewed the design, that the bridge, if erected, would be strong enough to carry the load and withstand the wind pressure. It might, however, be noticed that the stresses proposed, of $7\frac{1}{2}$ tons per square inch of gross sectional area, were greater than had hitherto been officially recognised by the Board of Trade authorities in England for parts in tension, although for steel having a breaking strain of 30 tons to the square inch such stresses were moderate, and had already been adopted in several cases.

Obviously the most doubtful point in the whole scheme was that of erection, and the estimate of cost appeared quite inadequate. Although no greater wind pressure need be feared than at the Forth Bridge, where it was concentrated in the narrow passage between the hills on either side, the force of the waves would obviously be much greater in the Channel. The floating breakwaters would be entirely dependent on the anchorage, and

from the experience already gained in the building of piers and breakwaters on the English coast, it could hardly be doubted that some of the plant and structure would be destroyed during progress. The distances to a harbour of refuge would be too great to allow barges, pontoons, and rafts to be removed when a storm was threatened, and these risks would be particularly enhanced during the floating of the heavy structures, as proposed.

The weight of the metallic work, including that in the plant and machinery, was given at 1,000,000 tons, and the cost was estimated at 480,000,000 francs, or 480 francs per ton = £19 per ton. Or, if the sum of money be divided over the permanent work only, weighing 771,000 tons, it gave £25 per ton. Considering the risks involved, it was probable that at least 25 per cent. would have to be added to this estimate to reach the sum at which experienced contractors would be willing to undertake the work. The hours of effective labour for men engaged so far from the shore, and at such considerable heights above the sea-level, would alone raise the cost beyond the ordinary rates.

It might be taken as certain that the cost of the bridge would much exceed that of the tunnel.

Mr. Thomas Curtis Clarke (New York) observed that, as a matter of theoretical engineering, this paper had much interest. Before it could have any practical bearing upon human affairs, several assumptions would have to be made.

Assume that the fears of the British public, of invasion from the construction of a tunnel under the Channel, would not be excited by the construction of a bridge over the Channel, and hence that Governmental permission could be got.

Assume that a congress of maritime nations would allow of the obstruction of piers in a stormy sea, full of strong currents, and subject to heavy fogs.

Assume that capitalists could be found daring enough to procure £34,400,000, and promises of more, in face of the dilemma that either the scheme would not pay, and the money would be lost, or, if it did pay, then a tunnel would be built for a quarter of the cost.

Assume all these things, and then the scheme became one of practical engineering, but not until then.

If Mr. Clarke were to criticise it in advance, he would say:

It was vain to talk of preparing foundations to carry nine tons per square foot by sending down workmen in compressed air to a depth of 180 feet, and possibly more. It must be done by machinery worked from above the water-surface.

If there were merely soft materials to be removed, and the piers were held up chiefly by side friction, as at Hawkesbury, N.S.W., or if a level bed of indurated gravel, resting on rock, could be secured, as at the Hudson River Bridge at Poughkeepsie, U.S.A., then he would say that the depth of the foundation, be it 180 or 280 feet below tide, would not prevent a safe result being obtained.

But suppose the hard material were of irregular surface, and needed to be levelled so as to give uniform bearing over the whole area of foundation. What then? This would involve the use of novel and untried machinery; and it was to be regretted that Mr. Hersent had not given some more definite description of his proposed methods than merely to say that "there will be no necessity to remain inactive, for, owing to its rotary structure, the ground can be acted upon by means of rotating machinery that can be set in motion from the platform, or it may be cleared and levelled beforehand by means of special machinery."

Suppose the foundation levelled and the caissons placed, then came the filling of it with concrete. Here the difficulty occurred, that if the filling were done through compressed air, or by water-tight boxes lowered from the surface, the operation would be a slow one. If a funnel or *tremie* were used, Mr. Hersent merely suggested that it would be necessary to pour in 120 cubic metres of concrete in fifteen to twenty minutes. Would any engineer skilled in this kind of construction say that this could be done, and still make a good solid artificial stone, capable of supporting six to nine tons per square foot?

The summary of this conclusion was that nothing proposed by Mr. Hersent was impossible, but that it would take much more time and money than he seemed to have estimated. Suppose the piers, or some of them, successfully completed, they then came to the question of erection.

It was interesting to an American engineer to read in the paper that the designs of the superstructure of Messrs. M. Schneider & Co., of Creusot, proposed that "the various parts of the bridge will reach the working yard in as complete a condition as possible. A greater or less number of works may be applied to

manufacture these different parts, in order to avoid the necessity of rapidly calling into existence a regular industrial town on a desert part of the coast. The fitting together of all the pieces can be mainly done in the work-yards."

It was very interesting to see this method endorsed by the consulting engineers, Sir J. Fowler and Mr. B. Baker, as it was the exact reverse of that used by them at the Forth Bridge. Experience had probably convinced them that the American methods of bridge-building, where all the fitting was done at the shops, and none at the site of erection, saved much time.

Two methods were suggested of erecting the bridge. One was to put it together in pontoons on shore, as was done with the 416-foot spans of the Hawkesbury Bridge, and then to tow it out to the site and raise it, as the Britannic Bridge was raised, in one piece, by hydraulic lifts.

It seemed to Mr. Clarke that to propose to tow a span 1312 feet long, and over 200 feet high, weighing 9580 tons, for fifteen to twenty miles, out into the rough seas which prevailed in the English Channel, was one more creditable to the daring than to the wisdom of its projector.

The other plan, of putting in intermediate temporary pieces, and then cantilevering out so as to reach the permanent piers, and afterwards beyond, was perfectly practicable and safe. It apparently would cost more than the other way, but really it would cost less.

The design of the spans was ingenious. The A-shaped cross section was good. The design of the "laced" Warren girder was novel and excellent. Of course, if Mr. Clarke were the designer of the bridge, being a Yankee engineer, he should use eye-bars and pins to connect together the main members. This was perfectly practicable, for by increasing the number of pieces in cross section, the connection could be made by pins and bars, such as the Union Bridge Company of New York were now prepared to make. These were 2 inches by 10 inches, and 65 feet long, with pins 9 inches diameter, and heads 24 inches across.

By the use of those connections, the strains would be determinate; while with the great number of rivets necessary for that mode of connecting the braces to the chords, even Professor Rankine, if he were alive, could not determine which rivets were working and which were idle.

# ON GASEOUS FUEL.

By Sir LOWTHIAN BELL, Bart., F.R.S.

For obvious reasons, when power is once generated, the sooner it is applied to the duty it has to perform the better. In like manner, that form of motion known as heat, does its work most economically when the same rule is observed. Of course, it often happens that a sacrifice has to be made, in order to meet the circumstances of particular cases. A steam-engine of moderate size is often seen storing up its energy in a hydraulic accumulator, so as to transmit it when wanted to a purpose far beyond the power of the prime motor directly applied. Again, for the Siemens furnace 15 to 30 per cent. of the heat of the coal is devoted to conversion into the gaseous form, in order that the latter, and the air required for its combustion, may be made to serve as vehicles for returning heat to the work to be performed. This is done because, without this stimulus, the temperature obtained by burning coal in the ordinary way would not suffice for the object in view. In the hydraulic accumulator, and in the Siemens furnace, there is a considerable sacrifice, but it is one which, for the reasons given, is quite justifiable.

I have been led to make these introductory remarks, in consequence of having been requested by the Council of the Iron and Steel Institute, to prepare a paper on a gaseous fuel known as water-gas. The compound nature of water was discovered by Cavendish and Lavoisier towards the end of the last century, and in 1804, Fourcroy mentioned the fact of hydrogen being separated from it, by contact with heated charcoal. Eighty-five years afterwards, the product of this reaction has been brought largely under public notice, and it is because the natural laws to which I have briefly alluded, have been, to some extent, lost sight of in the recommendations advanced in favour of water-gas, that I have complied with the wishes of my colleagues.

The gaseous fuel used in the Siemens furnace is known under the name of "producer-gas," and the manner of its manufacture is too well understood to require any description on the present occasion. It varies in composition somewhat, according to the kind of coal employed. For my purpose, it will be assumed for making the gas that we have to deal with a specimen of coal consisting of 70 of fixed carbon, 16 of coal gas, accompanied by 14 of ash, oxygen, and nitrogen.

The producer-gas so obtained will consist by weight of 16 parts of coal gas, 163·3 carbonic oxide, and 222 of nitrogen. Using the centigrade unit in the calculation, 7200 calories will be taken as the heat equivalent of the coal employed for the gas I am about to examine, and it will be assumed that the latter is received at the regenerators of the Siemens furnace, *after being cooled.*

We have then to consider:—

| | | |
|---|---|---|
| 100 of coal × 7200 calories, equal to . . . . . . | | 720,000 calories. |

By the combustion of the producer-gas there is as follows:—

| | | |
|---|---|---|
| 16 of olefiant gas × 10,000 calories . . . | 160,000 | |
| 163·3 of carbonic oxide × 2400 calories . . . | 391,920 | |
| | | 551,920 |
| Difference . . . . | | 168,080 |

which difference is loss, and represents 23·3 per cent. of the whole.

In a recent publication dealing with the question we are considering, it is stated that "gas as an economical fuel has come among us, and that it has come to stay." In support of this opinion we are reminded of the immense service which the natural gas, in the United States, has rendered to industry.

Gaseous fuel, however, is not the stranger, at all events to the members of this Institute, which might be inferred from this language. I mention this, after calculating that something like 4000 million cubic feet of gases are daily consumed at the blast furnaces of Great Britain. As regards the American gas, which I saw in use so long ago as 1876 at Pittsburg, any comparison between it and a factitious gas is, in my judgment, entirely illusory. In Pennsylvania, a mere hole is bored in the ground; this taps the

subterranean store, which rushes to the surface under a pressure of 200 to 300 lbs. on the square inch, and the gas is then impelled along a pipe by its own elasticity, to the very furnaces at which it is to be consumed. To obtain producer- and water-gas, a much larger and infinitely more expensive hole or holes have to be dug and fitted with costly and powerful machinery. Besides the coal, worked at great cost, vast volumes of air, and great weights of water, have to be set in motion. The coal has then to be transported, often for many miles, along a railway, and converted into gas, mixed with an enormous volume of inert nitrogen, which instead of being an almost perfectly pure combustible substance like that found in America, is, in this case, mixed with an enormous volume of inert hydrogen.

It will be convenient here to describe, in brief terms, the process recommended for making water-gas. A capacious cylinder of iron is lined with fire-brick, and provided with the necessary apparatus for introducing the fuel, resembling in principle the cup and cone of our blast furnaces. The fuel employed is recommended to be in the form of coke, into which, after being lighted, a current of air is forced, until the whole mass is brought to a high temperature. The blast is then stopped, the orifice for charging is closed, and a jet of steam is passed through the now highly incandescent carbon. The steam is decomposed, its oxygen burns the carbon into carbonic oxide, setting free the hydrogen, and this mixture constitutes the so-called water-gas, which is stored in gas-holders, such as those used in ordinary gas-works. It consists of one volume of hydrogen and one volume of carbonic oxide, the weights being in the proportion of 1 to 14. A gas of this composition, where a very intense temperature is required, is for certain purposes very valuable, because, of all substances with which we are acquainted, hydrogen gives out, when burnt, the largest quantity of heat. As an example, while a unit of carbon, in forming carbon dioxide, affords 8000 calories, one unit of hydrogen generates 34,200 calories, in the formation of water.

Now, if by burning one unit of carbon we could generate one unit of hydrogen, the exchange effected in the water-gas apparatus might be a very profitable one. Such a condition of things would however be directly opposed to the known facts of the case.

Chemically the change in producing this water-gas is expressed by $H_2O + C = H_2 + CO$. Now, the heat required to tear away hydrogen from its associated oxygen in water is not less than that which is evolved when these two gases unite; hence $2 \times 34,200 = 68,400$ calories. The weight of the combining equivalent of the carbon required to effect the change is twelve times that of the two units of hydrogen, and the heat generated by this quantity of carbon being burnt to carbonic oxide is $12 \times 2400 = 28,800$. Thus something more than $14\frac{1}{4}$ units of weight of carbon will be required to generate one unit by weight of hydrogen.

Now as only six units of carbon are being burnt, in the cylinder, for this quantity (one unit) of hydrogen, it will easily be understood that the incandescent carbon, which has served to generate the water-gas, is very speedily cooled below the temperature required for the decomposition just described. When this point is arrived at, the steam is shut off, and air is turned on again, in order to obtain a store of heat ready for a further production of water-gas. Thus, it will be seen, the operation consists in alternately making producer-gas, which, when using coke, is a mixture of carbonic oxide and nitrogen, and water-gas, with which we are now more immediately concerned. In calculating the amount of heat required to supplement that generated before commencing to make the water-gas, all we need to know is the quantity of carbon burnt to the condition of producer-gas, and that which enters into the composition of water-gas. According to the work I have already quoted, 25 per cent. only of the actual carbon used enters into the latter, the other 75 per cent. being converted into producer-gas, containing 68 per cent. of inert nitrogen. From 25 parts by weight of carbon there will be generated of water-gas 62·50 parts, containing 4·16 of hydrogen and 58·34 of carbonic oxide. The producer-gas from the remainder (75 parts) of the carbon will weigh 551·19 parts, of which 376·19 will be incombustible nitrogen and 175 carbonic oxide. The following estimate contains the full quantity of heat these two gases are capable of generating by their combustion:—

| | | | |
|---|---|---|---|
| Water-gas | 4·16 of hydrogen from steam | ×29,400=122,304 | |
| ,, | 58·34 of carbonic oxide | = × 2,400=140,016 | |
| | | | 262,320 |
| Producer-gas | 175·00 of carbonic oxide | = × 2,400 . . . | 420,000 |
| ,, | 276·19 nitrogen | | |
| | 551·19 | Calories . | 682,520 |

Had the 100 parts of carbon been burnt direct, the heat generated would have been 800,000 calories.

Hence the loss is 14·68 per cent. Inasmuch, however, as coke was used, and the 100 parts may be taken to represent 150 of coal, we have to multiply this quantity by 7200 calories, rather a low product for coal, which gives 1,023,780 calories, thus bringing up the deficit to 37 per cent.

In employing coke as a material in the gas generator, there is not only the loss of combustible matter which is incurred at the coke-oven, but the labour, &c., in conducting the process of coking. It is obvious, therefore, that if coal is a suitable material, it is in that form that the fuel should be used, *i.e.*, if ever a large demand for water-gas should arise. I have been fortunate enough to receive an account from a Moravian work, containing the particulars of making 6,041,155 cubic metres of water-gas, in obtaining which 29,734,731 cubic metres of producer-gas was generated, in order to heat the contents of the apparatus in the manner described. It would thus appear that each metre of water-gas is accompanied by 4·92 metres of producer-gas. The analysis of the coal is not given; on this account, and for the purpose of more exact comparison with what has already been said, I will assume its composition to be that of the specimen already mentioned, viz., 16 of coal-gas, 70 of fixed carbon, and 14 of ash, oxygen, &c.

In the metre of water-gas, consisting of equal volumes of hydrogen and carbonic oxide, we have:—

| | | | |
|---|---|---|---|
| 500 litres of hydrogen . . . | = 44·8 grammes. | | |
| 500 ,, of carbonic oxide . . | =625·0 | ,, . | =carbon 267·8 |

The producer-gas consists of—

| | | | | |
|---|---|---|---|---|
| 370 litres | coal gas distilled in heating the carbon | = 206·83 grammes. | | |
| 1,440 ,, | carbonic oxide ,, ,, | =1,805·19 | ,, | =carbon 773·6 |
| 3,110 ,, | nitrogen ,, ,, ,, | =3,921·23 | ,, | |
| 4,920 | | 5,933·25 | | Solid carbon 1,041·4 |

In this, the nitrogen is about 63·2 per cent. of the total volume,

and 61 per cent. of the weight. The carbon in the coal gas amounts to 109·52 grammes, which is considered to remain unchanged in the producer-gas. The carbon thus burnt for the producer-gas is 2·88 to 1 for that in the water-gas, instead of 3 to 1, as allowed in the description, when coke was employed.

From these figures it follows that we are concerned with 1041·4 grammes of carbon, as carbonic oxide in the two gases, and 109·52 grammes, contained in the 370 litres, equal to 206·83 grammes, of coal-gas.

The heat capable of being produced by these two substances is—

Carbon, 1041·4 × 8000 = 8,331,200 + 206·88 coal gas × 10,000 = 2,068,800 = 10,400,000.

When converted into water and producer gases, we have to deal with the following quantities of heat by their combustion:—

| | | | | |
|---|---|---|---|---|
| Water-gas containing hydrogen from steam, | 44·8 | grammes | × 29,400 = 1,317,120* | |
| „ „ carbonic oxide, | 625·0 | „ | × 2,400 = 1,500,000 | |
| | | | | 2,817,120 |
| Producer-gas containing coal gas, | 206·83 | grammes | × 10,000 = 2,068,800 | |
| „ „ carbonic oxide, | 1805·19 | „ | × 2,400 = 4,332,456 | |
| „ „ nitrogen, | 3921·23 | „ | ... ... | |
| | | | | 6,401,256 |
| | | | | 9,218,376 |

These two sets of numbers show, therefore, a loss of 11·36 per cent. in gasifying the coal.

It is perhaps worth comparing the assertion made in the pamphlet, in general terms, as to the relative proportion of carbon received in the form of water-gas and as producer-gas.

In the equation $H_2O + C$, we have $H_2 + CO$ for water-gas.
„ „ $O_3 + C_3$, „ $3\ CO$ for producer-gas.

The weight in the two equations of H is 2, and that of carbon 48, or 1 of H to 24 of carbon. Of oxidised carbon, in the example just examined when using raw coal, there was in the gases 44·8 of hydrogen, and 1041·51 or 23·24 of carbon, for 1 of hydrogen. Now, the heat of 24 parts, by weight, of carbon burnt to carbonic oxide means 57,600 calories, which have been expended to obtain 1 part of hydrogen, which, when burnt to steam, is worth 29,400 calories—the loss being, therefore, nearly 50 per cent. of the heat generated, in order to obtain the single unit of hydrogen.

* Hydrogen burnt to water gives 34,200 calories, and to steam only 29,400 calories.

Hitherto I have only spoken of the loss of heat involved by gasifying the fuel before using it, and as coal is cheaper than coke, we may confine ourselves to that, as the material to be used. It is, however, not coal, but gas that we have finally to deal with, and we must consider the cost of conversion. According to the return I have received from Germany, each ton of coal treated cost, in its gasification, no less than 12s. 2½d., made up by the following items :—

| | £ | s. | s. | d. |
|---|---|---|---|---|
| Labour . . . . | 1096 | 14 | 2 | 11½ |
| Steam . . . . . | 1286 | 12 | 3 | 6¼ |
| Fire bricks and clay . . | 79 | 14 | 0 | 2½ |
| Stores . . . . . | 113 | 16 | 0 | 3¾ |
| Repairs . . . . . | 369 | 8 | 1 | 0 |
| Sundries . . . . . | 34 | 10 | 0 | 1 |
| Interest and redemption . . | 1500 | 0 | 4 | 1½ |
| | 4480 | 14 | 12 | 2½ |

It is not our usual practice in this Institute to consider purely commercial questions, but the substitution of coke or coal by gaseous fuel is one which seems to involve some necessary reference to the question of cost.

In the pamphlet to which I have more than once referred, the expense of converting coke into the two gases is such that it works out, per ton of the coke used, as follows :—

| s. | d. | |
|---|---|---|
| 1 | 0·84 | for labour. |
| 1 | 5·17 | interest and depreciation. |
| | 2·17 | sundries. |
| 2 | 8·18 | |

The labour and other expenses at the Moravian work appears to me very high, and with this observation I must leave this question of cost to be decided by members themselves.

It is stated that solid fuel, under ordinary circumstances, only gives a useful effect of 20 and 25 per cent. of the total heat units capable of being afforded by the coal, whereas as high as 90 per cent. can be had from gas, qualified, however, by the statement that it must have a high percentage of combustible gas, and a great calorific intensity. This, of course, must mean the water-gas alone, for the producer-gas contains, as we have seen, 63 per cent. of inert nitrogen, and very little pure hydrogen; but it must be remem-

bered that this less important combustible gas represents something like 68 per cent. of the heating power of the two gases, against 32 contained in the water-gas.

I am, however, at a loss to understand whence this inference is drawn as to the inefficiency of solid fuel. The raising of steam, and smelting the ores of iron, may certainly be included within the category of "ordinary circumstances," and yet it is no uncommon thing for fuel to evaporate 60 per cent. of its theoretical quantity of water, and, as regards our blast furnaces, having regard to the chemical conditions to be observed, 90 per cent. of the full power of the fuel is accounted for by the duty performed.

To account for a supposed inferiority of solid fuel, it is assumed by the author, from whom I am quoting, that it is imperfectly oxidised. I have to do with a large number of boilers fired with coal, and at the Clarence Works we frequently consume 120 million cubic feet of blast furnace gas per day. I am prepared to assert that oxidation, in my experience, is as complete with the one kind of fuel as with the other. The quantity of heat evolved by each is, of course, easily ascertained—the only disturbing cause in any comparison between the two is the volume and temperature of the gases resulting from combustion. In this particular, no doubt, the net loss is in favour of water-gas, because the exchange of carbonic oxide for hydrogen necessarily reduces the weight of the chimney-gases passing away.

I propose now briefly to summarise the results in the following manner:—

1st. A specimen of coal, containing 70 per cent. of fixed carbon, 16 per cent. of coal-gas, and 14 per cent. of ash, nitrogen, &c., will be examined in a calorific point of view, and its power stated when simply burnt in an ordinary furnace.

2nd. Producer-gas, as supplied to the open-hearth steel furnace, obtained from the same coal, and its heating power also ascertained.

3rd. The same coal converted into water-gas and producer-gas by the processes described, and the united power of these two products calculated as before, on the supposition that for 1 of carbon in the water-gas 3 of carbon is found in producer-gas.

1. Coal as burnt in an ordinary furnace:—

| | Calories. |
|---|---|
| 100 parts, yielding 7200 calories per unit = . . . . . | 720,000 |
| Chimney-gases, estimated after making the necessary allowance for oxygen in the coals, 1129 units × 427° c. × ·24 Sp. heat = | 115,700 |
| Loss in this case by chimney-gases is equal to 16·07 per cent. | |

2. Producer-gas from the same coal as that used in Siemens furnaces, without the addition of steam.

| | Calories. |
|---|---|
| 70 of carbon will give 133·33 of carbonic oxide × 2400 = | 391,992 |
| 16·00 of coal-gas × 10,000 = | 160,000 |
| Sensible heat transmitted to furnace | 62,411 |
| | 614,403 |
| Heat in chimney-gases, 1129 × 377° c. × ·24 S. heat = | 102,151 |
| Loss at the chimney equal to 16·61 per cent. | |

In the former statement respecting producer-gas, no note was taken of the sensible heat, because it was wished to compare the heat evolution with the water-gas process, where the gases are cooled.

3. Water-gas and its accompanying producer-gas:—

| | Calories. |
|---|---|
| Water-gas, 17·5 of carbon = carbonic oxide, 40·83 × 2400 = | 97,992 |
| Hydrogen from steam . . 2·926 × 29·400 | 86,024 |
| | 184,016 |
| Producer-gas, 52·5 of carbon = carbonic oxide, 122·5 × 2400 | 294,000 |
| Coal-gas . . . . . . 16 × 10,000 | 160,000 |
| | 454·000 |
| Sum of heating power of water-gas and producer-gas | 638,016 |

Heat in chimney-gases assumed to be of the same temperature as that when burning ordinary producer-gas.

779·7 × 377° × ·24 S. heat = 70,547 calories = 11·05 per cent.

These figures intimate that each 100 units of the three kinds of fuel burnt there is afforded by—

Coal, 83·93; ordinary producer-gas, 71·14; water-gas and its producer-gas, 78·80.

Of course, it will be readily understood that these results are not given as effective; but the loss, at the same description of work, say for raising steam, being considered identical, the relative value of each is assumed to be as above stated.

In cases, however, where an intense temperature is required in order to do the work in hand quickly, water-gas may be highly

advantageous. Some years ago I had an opportunity of seeing such an application at Essen in the welding of corrugated boiler tubes, and the work was admirably done.

A very important application of water-gas is mentioned, viz., for illuminating purposes. For this object the gas, itself destitute of any value in this direction, is made to heat filaments or stems of magnesia. These become so brightly incandescent as to vie, it is alleged, with the electric light, and, in consequence, water-gas is largely used for lighting in the United States, instead of coal-gas.

I have nothing to guide me in forming any trustworthy idea of the relative quantity of water-gas required in comparison with ordinary gas for a given amount of light. In the pamphlet already named, 9,000,000 tons of coal is given as the yearly consumption among gasworks in this country; and upon one occasion it was mentioned that a volume of coal-gas, which would require a 36-inch pipe for its transmission, might, in the event of water-gas being employed, be conveyed in one of 1¼-inch. If this be true, it means that water-gas supposing the friction to be the same in each case, which is far from being the fact, is at least 810 times as powerful as coal-gas, which is probably a mistake.

A good deal of stress is laid on the application of water-gas to the manufacture of open-hearth steel. I doubt whether, in an operation where a more moderate heat suffices, it can be worth while to seek to obtain one of a more intense character. At one steel-work with which I am concerned, the ingots were formerly heated in Siemens furnaces. These were abandoned, and ordinary coal-fed fires used in their place, and the saving of fuel effected by the change has been very marked. I should therefore be somewhat surprised if, with longer experience, there will be found any material advantage in using the water-gas in open-hearth steel furnaces.

It would appear from the figures used for representing the relative values of ordinary producer-gas, compared with water-gas and its accompanying producer-gas, that the sum of the latter gives a better result than the former, viz. 78·80, as against 71·14. The difficulty, however, will be, when the richer gas is wanted, to find a market or use for the poorer, which, it must be remembered, represents 71 per cent. of the heating power of the whole. Looking

at the question broadly, it seems clear that nothing can be gained in a calorific point of view by the proposed gasification of our fuel, and that to the loss in this respect has to be added a very sensible amount by the cost of the operation. This observation has reference to the general application of heat, and to that only. The limit, therefore, of gaseous fuel will be fixed by the opportunities in which a more expensive form of intensely hot fuel like water-gas is wanted, and to this extent there will probably be opportunities enough of utilising the producer-gas. For general use, however, I think solid coal is not likely to be superseded by any form of factitious gaseous fuel.

## POSTSCRIPT.

Since referring to certain information concerning the manufacture of water-gas in Moravia, I have received from my friend, Mr. Paul Kupelwieser, the director of the establishment at Witkowitz, permission to use his name as my authority for certain statements contained in this communication.

I find I was in error in supposing that coal had been used in the generators, the fuel employed being small coke valued at 10s. per ton, whereas in a letter to our Secretary it is given at 13s. 5·4d. Coke (from gasworks) is also recommended to English water-gas makers; but if ever the day should arrive when, for heating purposes, gaseous has to take the place of solid fuel, and water-gas has to displace ordinary coal-gas, either raw coal must be employed in the generators, or the great waste of heating-power, already mentioned in coking the coal, must be incurred.

Mr. Kupelwieser properly observes that the cost of water-gas must largely depend on the value which is attached to the producer-gas, and he divides the expense in the following manner:—

| | Florins. |
|---|---|
| 29,734,731 cubic metres of producer-gas at ·18 kreutzers per metre . | 53,522 |
| 6,041,155 ,, ,, water-gas at ·673 ,, ,, . . | 40,653 |
| Total cost . . . | 94,175 |

Now, the total weight of combustible matter, viz., carbon, in the producer-gas is, by calculation, 5898 tons, and its value, based on the price of the cubic metre, is 18s. 1¾d. per ton.

The aoove quantity of water-gas is estimated to contain:—

| | |
|---|---|
| Carbon . . . . . . . . | 1619 |
| Hydrogen . . . . . . . . | 270 |
| | 1889 tons, valued at 43s. per ton. |

If we take 1000 kilogrammes as being equal to one ton, the heat from this quantity of carbon, as it exists in the producer-gas, viz., as carbonic oxide, may be stated as representing (1000 × 5600 calories) 5,600,000 calories.

This quantity of heat could be obtained by the combustion of 700 kilogrammes of carbon (700 × 8000 being 5,600,000 calories). Now this carbon may probably be taken as equivalent to 800 kilogrammes of the small coke, and costing therefore about 8s., against 18s. 1¾d. for the same amount of heating power in the form of producer-gas.

The water-gas contains in 1000 parts:—

| | Calories. |
|---|---|
| 857 of carbon, which × by 5,600 = | 4,799,200 |
| 143 of hydrogen „ × by 32,480 = | 4,633,200 |
| | 9,432,400 |

To produce this quantity of heat from pure carbon we should require $\frac{9,432,000}{8000} = 1179$ kilogrammes of this substance. If we assume this quantity of carbon to represent 1350 kilogrammes of the small coke, this at 10s. amounts to 13s. 6d., which appears capable of affording the same quantity of heat as 857 of carbon and 143 of hydrogen, in the form of water-gas costing 43s.

From what has preceded, I have calculated that if a given quantity of heat, from coke burnt direct, costs 100; that from water-gas and producer-gases, according to Mr. Samson Fox's estimate of 2s. 8d. for gasification of the carbon, will be about 120, and according to Mr. Kupelwieser of 13s. 2d. about 200.

These calculations are my own, worked out upon the figures given by Mr. Kupelwieser, and they both tend to show how largely the cost of fuel was increased at Wilkowitz by the process of gasification. This gentleman then goes on to observe that, according to his experience, gas obtained from coal in good producers gives perfectly satisfactory results in open-hearth furnaces, and that in nearly all cases such furnaces are worked more economically with

ordinary producer- than with water-gas. At the same time he allows, that which I previously admitted, viz., that for some purposes water-gas may be profitably employed.

From another friend I learn that for each metre of water-gas, four metres of producer-gas have to be made. He would not consider it advisable to convert coal into gaseous fuel for the purpose of raising steam. The producer-gas obtained in manufacturing the water-gas is used in puddling furnaces and in heating large blocks of metal weighing as much as 50 tons. In the open-hearth steel furnaces a mixture of the two gases is employed, and, for steel intended for castings, this mode of treatment is considered very good, because the high temperature afforded by the water-gas, he says, enables the workmen to have the metal so fluid that it runs with ease into castings, however intricate.

## *DISCUSSION.*

Mr. JOHN HEAD said he was sure the members were very grateful to Sir Lowthian Bell for the able manner in which he had treated the subject, bringing it forward, as he had done, in a form which they could quite understand. A great deal of confusion had been created in the public mind by the recommendation of water-gas for various uses to which it was not applicable. It was assumed that, because water-gas would give a higher initial temperature of combustion, therefore it must be better than producer-gas for furnace purposes. That was not so. The real question was, what was the loss of heat in the chimney; and comparing the one gas with the other, the only difference between water-gas and producer-gas was, that the weight of the gases going up the chimney, at the same temperature in both cases, would be less in the case of water-gas than in the case of producer-gas. But, in considering that subject, they must not forget another point, namely, that in the combustion of water-gas a large quantity of steam was formed, and that the latent heat of this steam represented an amount of heat which could not be recovered in furnace work. He had made a calculation, based upon theoretical considerations, as to the value of water-gas as compared with producer-gas, and he had found that, when everything was taken into account, water-gas was about one-half per cent. better than producer-gas; or, in other words, 100 tons of carbon converted into producer-gas would yield the same result as 99½ tons converted into water-gas, and that was the only advantage that he could find. Then there was another point, namely, the question of cost. He had had no experience in working furnaces with water-gas, and was entirely dependent for his information on that subject upon the circulars which had been issued. He had made a calculation for Mr. Siemens, based on the figures given by the friends of water-gas, and he found that to melt two tons of steel, and to do a certain amount of other work, it would cost 18s. 3d. with water-gas, and only 10s. 6d. with producer-gas. The details of this calculation had been sent to

the technical journals by Mr. Siemens in a letter, dated 8th of August 1888, and there was, therefore, no need to repeat them on that occasion. Sir Lowthian Bell, in his paper, had carefully warned them that, in comparing the different gases or fuels used, they must not take the figures given as effective. He (Mr. Head) wished to impress upon the members the necessity of remembering this, because if they did not they would get very much out in their calculations. They ought also to take into consideration the temperature at which a furnace was required to be worked. In a calorimeter, much better results could be obtained from a given weight of solid fuel than from the same weight of fuel entirely converted into gas in the Siemens producer or with the water-gas apparatus; but when they had to deal with steel-melting and other high-temperature furnaces, coal would be quite inapplicable. He thought that Sir Lowthian Bell had taken the chimney temperatures in the case of coal-fired furnaces quite low enough, if not too low; and it seemed to him that such a temperature as 427° C. could not be realised in a heating furnace.

Sir LOWTHIAN BELL: That is centigrade.

Mr. HEAD said that Sir William Siemens took 370° C. as the temperature of the gases passing away up the chimney from the regenerative gas furnace.

Sir LOWTHIAN BELL: Probably it would be the same in all.

Mr. HEAD: Sir Lowthian Bell had said that at one steel-works with which he was connected, the ingots were formerly heated in Siemens furnaces, which were abandoned for ordinary coal-fired furnaces, and a saving of fuel was effected. He (Mr. Head) must be allowed to say that such a substitution would not have been profitable if the Siemens furnace had been properly worked. Perhaps it would be thought that he had an interest in saying this. He admitted that he had an interest in saying what he did, but, at any rate, the members would listen to his reasons. If he had regenerative gas-heating furnaces at his

disposal he should use them, and use them with great advantage, because the consumption of fuel would certainly not be more than one-half of what it was in the ordinary furnaces. The capital expenditure involved in the construction of furnaces for dealing with large quantities of metal would certainly weigh against the adoption of the old form of Siemens furnace; but on the following day he hoped to bring forward a new form of Siemens furnace which would overcome that objection. With regard to the heating furnaces referred to by Sir Lowthian Bell, he did not know what particular furnaces were referred to, but he had seen regenerative gas-heating furnaces in the north of England that were not worked as they should be; the valves were red hot, and probably much gas was going up the chimney. They all knew it was quite possible that with the best piano a most horrible noise might be made. In like manner, some persons managed with the Siemens furnace to get the most unsatisfactory results. It required more intelligence to work it than any other furnace. Manufacturers often looked upon the producer-man as a labourer, which was not a right thing to do. He understood a labourer to mean a man who removed material from one place to another, which was a simple mechanical action; but in the case of the producer-man, he had to use a certain amount of discretion; he must not overcharge the producers, but must keep them up to the proper mark; so that he ought to be looked upon as an artisan to some extent, and paid a little more than an ordinary labourer. If they did not do that, they would find it necessary to have foremen over the producer-men, for the purpose of seeing that the producers were all kept in order. Unless they did that, they would find a great deal of difficulty in controlling the working of the producers, and a great waste of fuel would be the consequence. Then there was another point upon which Sir Lowthian Bell had touched, namely, utilising the sensible heat of the gases leaving the producer in connection with the form of Siemens furnace having four regenerators. He (Mr. Head) had also made a trial in that direction, obtaining, however, but indifferent results. It had been pointed out to him that a loss of fuel was occasioned by cooling the gas from the producer, and he determined to make a trial application of gas supplied hot to the valves of furnaces.

This trial application was made at a large glass-melting works under his control. He put up two furnaces, each holding about 120 tons of glass, that is to say, 240 to 250 tons of metal in a molten condition; for this purpose a high temperature was required, and he found that the furnaces did not work at all satisfactorily. First of all, the valves got very hot, and were an endless source of trouble; and, secondly, the gas was so expanded by heat that it was very difficult to supply the furnaces with a sufficient quantity. He worked the furnaces a fortnight, and by standing by them day by day he just managed to make them do the work required; but it was impossible to expect a furnace-man to do this. By adding a cooling tube to each set of producers all trouble ceased, and they saved about 4 tons of coal per week, equal to about $3\frac{1}{2}$ per cent. of the consumption, which showed that the alteration was in the right direction. Another beneficial result was that the valves, pits, flues, and chimney were not so hot as before; and, to his mind, it was conclusively proved that the sensible heat of the gas attempted to be utilised only went up the chimney. When they considered the action of the Siemens furnace with four regenerators, this could easily be explained. Taking the weight of the outgoing gases at, say, a ton in five minutes, a certain amount of heat would be deposited in the regenerators, which, to be completely utilised, would require the same weight of outflowing gas and air to enter the opposite pair of regenerators in the same space of time. It would be understood that, the outgoing currents heating a pair of regenerators both to the same temperature, the inflowing gas and air should each be capable of taking up the same amount of heat. Supposing that the producer-gas used was not cooled, it would not be able to take up all the heat previously deposited in the gas regenerator, with the result that, on the reversal of the currents, a considerable quantity of heat would be lost up the chimney, and, on its way there, would heat up and probably damage the gas-reversing valve. It might be added that, at whatever temperature the inflowing gases enter the regenerators, the heat of combustion within the furnace would be exactly the same, inasmuch as the temperature at which they and the air for combustion reached the furnace was regulated by the temperature of the outflowing gases.

Mr. WILDY (Leeds Forge) said it was stated in the paper that from "15 to 30 per cent. of the heat of the coal was devoted to convert the coal into the gaseous form." From numerous records, the larger percentage was more correct for producer-gas; and from many analyses of producer-gas, even 60 per cent. was above the value of the heat-units in the gases compared with the heat-units in the fuel. The object of the conversion of the solid fuel into gaseous fuel was only partially stated by Sir Lowthian when he said: "This is done because, without this stimulus, the temperature obtained by burning coal in the ordinary way would not suffice for the object in view." A further and much more important object was to convert the fuel into a more manageable form, and that its employment might be made, wherever it was needed, under exact regulation, and with a minimum of labour and dirt. A temperature being obtainable with the gaseous fuel which was absolutely unattainable with solid fuel, proved that, where temperature was required, gaseous was the only form in which to use fuel, and where heat was required to be under control, gas offered the readiest means of producing and controlling the heat. The author again said: "For obvious reasons, when power is once generated, the sooner it is applied to the duty it is to perform the better. In like manner, that form of motion known as heat does its work most economically when the same rule is observed. Of course, it often happens that a sacrifice has to be made in order to meet the circumstances of particular cases." And, later on, he stated: "The natural laws to which I briefly alluded have been to some extent lost sight of in the recommendations advanced in favour of water-gas." Now, in the production of producer-gas, the heat necessary to volatilise the carbon was entirely lost; whereas, in making water-gas, it was this very waste of the ordinary producer-gas, coupled with a portion of the glowing carbon, which was employed to decompose the steam and produce water-gas. This was keeping very much in sight the earliest possible application of the heat which, without this application, was absolutely lost. Then, in Sir Lowthian's calculations of the comparative calorific effect of producer-gas, and the fuel from which it was made, he took credit for the whole of the carbon and hydrocarbons in the fuel, while it was well known that there was a large percentage of loss by conden-

sation in the gas tubes and flue, and that, instead of the producer-gas at the furnace showing a loss of 23·3 per cent., any number of analyses showed losses of from 30 to 40. Sir Lowthian's description of an American gas-well was too humorous to be taken seriously—a hole in the ground, a pipe, and a furnace, and there you are. The reference to natural gas and other gas having come among them was not made with the idea of comparing natural gas, or its cost or value, in any way with either producer-gas or water-gas, but simply to show that the whole of the metallurgical world had its eye very much on gas and gaseous fuel. But, as to the cost of the natural gas being very much less than that of water-gas could possibly be, there being only a hole in the ground, and a pipe to a furnace, the cost of supplying carburetted natural gas in the town of Pittsburg, giving from 22 to 24 candle-power, was a dollar per thousand cubic feet; whereas, at the Leeds Forge, with which he was connected, the whole of the lighting was done with water-gas, not carburetted, and the cost, including the provision of keeping up the magnesia combs, did not exceed sixpence per thousand cubic feet. The working out of the figures of the calorific value of gases produced by the water-gas generator was certainly very accurate; but when it came to be concluded, as was done in a part of the paper, that, because they were using coke, the cost of 100 parts must therefore be taken as equal to 150 of coal, he thought the author was taking liberties with their statements which were unwarranted and untenable. They only used coke for convenience. Coke was not necessary: it was, in their case, convenient. They used coke which had been already deprived of a portion of carbon and hydrogen, for the purpose not of making coke, but of making gas. From independent analyses which had been made, the loss was found to be only 11·5 per cent. Oven-made coke was not, and would not by choice be, used for water-gas: coal could be, and was, used at present, even working with small coal and refuse coke from other furnaces about a works he was acquainted with to the extent of 80 per cent. in the producer. The reason why the 20 per cent. of coke was put in was because it was there, and could not be used otherwise, but would be thrown away, as it was at present thrown away to the extent of thousands of tons in many ironworks. Some of the figures referring to the Moravian

works, while intending to be instructive, were most misleading. He had been in Witkowitz, and watched the producers there, and had received from the mouth of the engineer in charge very different statements from those now put forward by the author, as communicated to him by Mr. Kupelwieser. Some of those statements were published in the *Proceedings* of the Institute, and formed originally the subject-matter of a paper read before the Austrian Engineers' and Architects' Society. Other figures given by Mr. Kupelwieser were very interesting, as confirming in a marked degree the statements he had just made, that the loss in gasifying fuel with the water-gas producer was only 11·35 per cent., while he stated it to be 11·5 per cent., from their own experiments and calculations. The author stated in the course of his examination of the Witkowitz figures:—"It is, perhaps, worth comparing the assertion made in general terms in the pamphlet of the relative proportion of carbon received in the form of water-gas and as producer-gas:—

In the equation $H_2O + C$, we have $H_2 + CO$ for water-gas.
,, ,, $O_3 + C_3$, ,, $3\,CO$ for producer-gas.

The weight of the two equations of H is 2, and that of carbon 48, or 1 of H to 24 of carbon. Of oxidised carbon in the example just examined, when using raw coal, there was in the gases 44·8 of hydrogen and 1041·51 of carbon, or 23·24 of carbon for 1 of hydrogen. Now, the heat of 24 parts by weight of carbon burnt to carbonic oxide means 57,600 calories, which have been expended to obtain 1 part of hydrogen, which, when burnt to steam, is worth 29,400 calories—the loss being therefore, nearly 50 per cent. of the heat generated in order to obtain the single unit of hydrogen." It was here assumed that the whole object from first to last of making water-gas was to produce hydrogen—a fallacy, anything but philosophic. Taking the author's figures, what did they get? They got $H_2$ $C_{48}$, or $H_1$ to $C_{24}$. The 24 parts of carbon burnt to carbonic oxide meant 57,600 calories. Those 24 parts of carbon further burnt to carbonic acid equalled 134,400 calories, taking the hydrogen as 1, which, when burnt to steam was worth 29,400 calories, and adding this 29,400, brought the total to 163,800 calories. The 24 parts of carbon burnt to carbonic acid would

have produced 192,000 calories, the loss being 28,200, or 14·6 per cent., instead of 50 per cent., as stated in the paper. As had been admitted on all hands, gaseous fuel was one of the most perfect forms of fuel known, from its easy applicability, control, and cleanliness, yet the gases most usually employed showed a loss of at least 30 per cent. of the total heat-units in the fuel, and then gave a gas the flame of which was of far lower calorific intensity than the flame of water-gas, the proportion being about 1915 to 2839. The detailed statement of the cost of production of water-gas at Witkowitz was so extraordinary, and the cost per ton of gasifying the fuel so enormously high, that he could not but think that there must be some error, or that proper supervision had not been kept over the process. That it should cost 12s. 2½d. to gasify a ton of coal seemed enormous. It did not include the cost of the coal, but simply labour, steam, depreciation, wear and tear of plant, and sundries. That it should cost 12s. 2½d. to gasify, not to buy and gasify, a ton of fuel seemed ridiculous and absurd. Then there was a charge put down of £1286, 12s. for steam to produce water-gas, amounting to 3s. 6½d. per ton of fuel gasified. It was monstrous. If they would go through the figures, it would be seen to be impossible for it to cost that, even if they bought the fuel to produce the steam at £1 per ton. As to steam, a ton of fuel would decompose 980 lbs. of water on an average, and produce 35,000 cubic feet of water-gas, and 140,000 cubic feet of producer-gas. Therefore, to provide steam for gas-making, 980 lbs. of water had to be evaporated per ton of fuel. Then he would allow 980 lbs. further, which was some 35 per cent. more than was absolutely necessary, for engine purposes. They had to drive a blower, for example, and to consume a certain amount of steam, but 980 lbs. was ample. The two together made 1960 lbs. of steam. Dividing this by 9, it equalled 218 lbs. of coal, or roundly, 2 cwt. at 6s. The cost of fuel thus comes to 7¼d., instead of 3s. 6½d., which the authorities at Witkowitz had supplied to Sir Lowthian Bell. There was no question about it that the charges were extraordinarily high. He had gone through them carefully to compare them with their own costs. They were working water-gas plant day and night regularly, and had now had two years' experience, and he found that, on the average, Witkowitz was

working at rather over three times the cost of Leeds. Including everything, interest, depreciation, wear and tear, &c., their cost at Leeds did not come out as one-third of that at Witkowitz. Sir Lowthian Bell, in claiming for solid fuel the utmost efficiency in use, mentioned the blast furnace, in which, having regard to the economic conditions to be observed, 90 per cent. of the full power was accounted for by the duty performed. That could only be accomplished by the efficient capture and employment of the top gases, which represented more than half the total heat-value of the fuel in the furnace, thereby converting the blast furnace into a veritable gas-producer, and using the best part of the fuel in heating the blast for the furnace, raising steam, &c.; and it was found that the higher the furnace, the better the gas. By his comparisons, Sir Lowthian Bell had actually proved the point which it was the object of the paper to discredit, namely, that in a gas-producer they got the utmost out of the fuel. Coming to the summarised results, and working on the assumed composition of the fuel, they got for coal a total possible of 720,000 calories. Coal burned in ordinary furnaces, without excess of air, minus loss in chimney, and assuming perfect combustion, which was seldom or never attained, 604,300 calories, equal to 83·9 per cent. For producer-gas, Sir Lowthian Bell took credit for too high a quantity of calories, because it could only yield about 70 per cent. of the heat-units in the fuel. Therefore, instead of having 614,000, they only got 401,000, or 55·8 per cent. For water-gas, pure gas from the gas-holder, they had 567,469, or 78 per cent. Sir Lowthian Bell further stated: "In cases, however, where an intense temperature is required in order to do the work in hand quickly, water-gas may be highly advantageous." That was one of the conditions of an open-hearth furnace; and if the melting down and refining of the charge could be accomplished in a period represented by a fraction of the time at present required, the result would be an increased annual turn-over on the capital invested; and where water-gas was employed to increase the combustible percentage, the results had been most satisfactory. He had with him some papers which had been sent him by a friend who was working water-gas, and he would shortly give them the results of working water-gas and producer-gas mixed in a furnace, which was the way advised for certain purposes, and

also working solid fuel, which Sir Lowthian Bell held was the better method. In reheating the furnaces, working with mixed gas, the production per 12 hours was 35 tons; the coal used in the gaseous form, 9 tons, or 5 cwt. 0 qrs. $15\frac{1}{2}$ lbs. per ton. In the ordinary furnace, using solid fuel, the production in 12 hours was 16 tons 10 cwt., against 35 tons; the coal used as solid fuel was 5 tons 4 cwt., against 9 tons; the coal per ton of production was 6 cwt. 1 qr. $5\frac{1}{2}$ lbs., against 5 cwt. 0 qrs. $15\frac{1}{2}$ lbs., an economy of 18·4 per cent. in favour of mixed gas furnaces.

Mr. John Head inquired whether the gas furnaces used for heating the metal, which, according to Mr. Wildy's statement, was effected with a consumption of 8 cwt. of fuel per ton, as compared with a consumption of 13 cwt. per ton when the same work was carried out in a coal-fired furnace, were not regenerative gas furnaces.

Mr. Wildy: Undoubtedly.

Sir Lowthian Bell: What was the temperature?

Mr. Wildy said it was a reheating furnace. In the slab furnace producing the best iron for rolling to small dimensions *the production was* 10 *tons* 10 *cwt. per day of* 12 *hours;* using coal in the gaseous form, 4 tons 6 cwt.; or coal per ton of production, 8 cwt. 0 qrs. 22 lbs.; loss of material, 14 to 15 per cent; men required to work at the furnaces, 3. In the ordinary furnace, the production per hour was 5 tons 10 cwt.; coal used as solid fuel, 3 tons 12 cwt.; coal used per ton of production, 13 cwt. 0 qrs. 10 lbs., as against 8 cwt. in the gas-fuel furnace; men required to work the furnace, 4; economy of work by mixed gases, 39 per cent. Then there was a large reheating furnace, 19 feet 8 inches by 14 feet 9 inches. The only data he had were as to the time required, comparing solid fuel with gaseous fuel. Heating ingots of 20 to 30 tons with solid fuel required from 37 to 51 hours. In the gas furnace, with the same size of ingots, 24 to 33 hours—that was with mixed producer-gas and water-gas.

Sir Lowthian Bell: Mixed according to certain proportions?

Mr. WILDY: Mixed to suit the circumstances entirely. They did not use the same amount of water-gas in reheating furnaces as they would use under any other circumstances. It was necessary to mix the gas to suit the work in hand. In the crucible furnace, using mixed gases, the make was from 5 to 6 charges of soft steel, consisting of 40 crucibles, each holding 78·5 lbs., per 24 hours. In gas puddling the production per 12 hours was 7 tons 16 cwt.; using coal in the gaseous form, 3 tons 4 cwt.; coal per ton of production, 8 cwt. 0 qrs. 8½ lbs. In the ordinary furnace the production was 2 tons; coal used as solid fuel, 1 ton 16 cwt.; coal per ton of production, 18 cwt., against 8 cwt. in the gas furnace, showing an economy of 55 per cent. With regard to steel melting, he had all the data as to the composition, cost, charges, and so forth, but the part that was most interesting was, that 30 charges at least per week were made, each charge taking from 4 to 5 hours.

Sir LOWTHIAN BELL asked what was the weight of the charge?

Mr. WILDY: 15 tons. The furnace would stand from 300 to 350 charges. There were less repairs required when using mixed gas than when using ordinary Siemens gas. The steel made was subjected to the tensile test of from 25 to 50 kilos. per square millimetre, or equal to 20 to 30 tons per square inch; elongation, 20 to 30 per cent., varying, of course, with the composition of the steel.

Mr. EDWARD RILEY asked if Mr. Wildy could give the weight of coal per ton of production?

Mr. WILDY said that in the steel-producing furnaces, using the ordinary old-fashioned Siemens producer, they used 13 cwt. to the ton; and with mixed gases they used from 8 to 9 cwt. It varied a little with the quality of the fuel. They used a lot of refuse, and that rather varied. They used commoner fuel altogether. There was one point in Sir Lowthian Bell's paper which, he thought, ought hardly to be passed without notice. It was that which stated that "a volume of coal-gas, which would require a 36-inch pipe for its transmission, might, in the event of water-gas being employed, be conveyed by one of 1¼

inch." That statement by itself, without the context, either of what had been said or written, was very misleading. It made one think that, as Sir Lowthian Bell said, water-gas was at least 810 times as powerful as any other gas in the world. That was not what was stated in the pamphlet. It was wholly unwarranted. What was said was, that, provided it was necessary to force the gas to any considerable distance, as much gas could be sent through a $1\frac{1}{4}$-inch pipe, at ordinary gas pressure, as would pass through a 36-inch main, at ordinary gas pressure. He did not know whether it said under pressure, but he believed pressure was being spoken of at the time. The idea was to compress the gas to any extent and force it along; and that could be done. As to the application of water-gas to the Siemens furnace, Sir Lowthian Bell took some exception. He said, "A good deal of stress is laid on the application of the water-gas to the manufacture of open-hearth steel;" and further on, "At one steelworks with which I am concerned, the ingots were formerly heated in Siemens furnaces." There was a great deal of difference between heating ingots in Siemens furnaces and producing steel in the open-hearth furnace. In the one case they required a comparatively low temperature, and in the other a good high temperature, and as rapid action as they could get without oxidising the metal too much. Against continually increasing extensions of the practice of conversion of solid into gaseous fuel, Sir Lowthian Bell had expressed his opinion, in a manner that would lead one to think that the wish was father to the thought, that "solid fuel was not likely to be superseded by any factitious gaseous fuel." Coming to what was really the sting of the paper, the postscript, they had a proof of the great possibility of errors existing in the previous statement from Witkowitz as to the cost of converting a ton of fuel into gas. In a letter to the Secretary of the Institute it was stated that coal costing 13s. $5\frac{1}{4}$d. was employed; the author of the paper being informed by the same authority that small coke was used, valued at 10s. That was error number one, amounting to $34\frac{1}{2}$ per cent. Then, even small coke, which was valued at 10s., could be purchased in England for 6s. In other words, the cost of the fuel was put 66·6 per cent. too high. If the same system of error pervaded the whole table, the costs were not only most erroneous, but the deductions drawn by Sir

Lowthian Bell were untenable, even with regard to Moravia, and considerably more so with regard to England. But why, with the figures before him, with the results of English experience in water-gas production, figures obtained by actual working over extended periods by independent persons not connected in any way with the water-gas interest, Sir Lowthian Bell should go to Moravia for his data was incomprehensible. Under any circumstances, the figures from Moravia could not apply to English working; and though living there was remarkably cheap, from information that he had obtained, material was not. He had shown how unreliable were the figures upon which Sir Lowthian Bell had based his calculations of cost. The charges were three times higher than they would be in England. In charging fuel at 13s. 5¼d. which would cost about 6s., the statement that "coke at 36s. 5⅝d. per ton would produce heat as cheaply as water-gas" fell to the ground. It should be divided at least by 2½. The concluding remarks of the paper showed, first, that gaseous fuel gave perfectly satisfactory results; and when Mr. Kupelwieser informed Sir Lowthian that in nearly all cases such furnaces were worked more economically with producer-gas than water-gas, he forgot the previous statement in the paper read before the Austrian Engineers' Society by an official engineer of the Witkowitz works, in which the following facts were stated:—First, coke of poor quality was used; second, 86·7 per cent. of the disposable quantity of heat was obtained in the gases; third, the gas was exceedingly well adapted for use on the open-hearth; fourth, when using water-gas it was found that the open-hearth could be worked at about one-half the cost involved when ordinary producer-gas was used, even though, for equal heat evolved, the cost of the water-gas stood in the proportion of 1·77 to 1·72 for producer-gas. All those particulars appeared in the *Journal of the Iron and Steel Institute*, vol. i., 1887, pages 368–9. The concluding paragraph of the author's paper summed up and confirmed the statements which he (Mr. Wildy) had made. As far as his experience went, the statements and calculations made in the paper demanded some explanation and correction. He desired, however, to thank the author, and the President and the Council, for giving him the opportunity of explaining his views on the matter.

M. Kupelwieser said, as to the two different prices mentioned for coke, when Mr. Jeans wrote to him in the spring, making certain inquiries as to the cost of water-gas, they were using coke and not coal. They used their own coke, and at a price of 13s. 5d.; in the autumn they were using small coke which cost 10s. a ton. It was sometimes said that water-gas might be made out of anything that contained coal, cinders, ashes, and very small coal, which would otherwise be thrown away. It was, no doubt, possible, but so small a quantity would be made out of the material, and so large a plant would be required, that it would never answer the purpose. Mr. Sulzer, who was interested in water-gas, and had visited him at Witkowitz, had told him that he always used the best Westphalian coke, and he had found it the cheapest and best to work. It was true, however, that they could work with ashes. In a plant producing about 20,000 cubic metres a day they had a machine of 20 horse-power. In large works the amount, perhaps, was not estimated so high, but he could assure the members that large quantities of steam were required for producing water-gas. With regard to mixed gases, he might say that for Siemens furnaces they could, using producer-gas, easily have the temperature high enough; indeed, they might have it too high in some cases. Steelmakers knew well enough that very often the temperature was too high, and not too low. Many steel castings were spoiled because the temperature was too high. He, therefore, saw no advantage in using gas at a higher price for a purpose for which it was not necessary. With regard to the cost, as he had only just seen the paper, he was not prepared to give the complete details, but he might mention that 1000 cubic metres of water-gas cost little more than 1s. in Witkowitz.

The President said that, as M. Kupelwieser had not had the opportunity of examining the figures, and as the discussion would be adjourned until the following day, it would be better if he deferred his remarks until the next morning.

M. Kupelwieser said that 1s. per thousand cubic metres was not much dearer than at Westphalia. The economy of water-gas depended upon the value of producer-gas at the same time.

If the cost of producer-gas was a little higher, the water-gas became cheaper, and so on. He had no desire to prevent any one from trying water-gas, but he might say that he had himself tried it, and he should be glad not to have done so. There were, however, many applications of water-gas for which it might be very valuable, as at Essen for welding tubes, and many things of that sort.

Mr. J. E. Dowson inferred that the author of the paper wished to compare the result, theoretically rather than practically, of using gaseous instead of solid fuel, irrespective of what the particular cost of the coal might be. For instance, if they assumed that it cost 10s. a ton, the real question for consideration was, whether or not it were better to use the fuel in the solid or gaseous form. Personally, he was extremely glad to find that the paper dealt with the subject theoretically; but, as the author himself had admitted, it was impossible not to take account of some of the practical bearings as well; in fact, if it were not for that saving clause, he feared that the case of gaseous fuel would be rather a poor one, but if they took some account also of the practical points at issue, the verdict would surely not be altogether against gaseous fuel. Of course, one had to recognise that out of a given weight of fuel they could only get a certain number of heat-units, whether the fuel be burned directly as solid fuel, or whether it be converted first into gas. They also knew that a certain amount of the heat energy of the fuel had to be expended in the process of conversion. It should, however, be remembered that, from the practical point of view, it was not possible to burn solid fuel without introducing something like twice the volume of air theoretically required for its combustion, in order to drive away the products of combustion from the fuel, and supply it with a sufficiency of oxygen. Moreover, this supply of air had to be brought in by means of a strong chimney-draught, which caused a rapid withdrawal of the heated currents, and naturally led to a further loss of heat. With gas it was not necessary to have so large an excess of air present, nor was it necessary to have a strong chimney-draught. Further than this, the gas could, when required, be heated before combustion by means of the outgoing products, but with solid fuel this

was impossible. These were gains in favour of gas; but, on the other hand, the water-gas system, which had been much referred to, had, in his opinion, two distinct disadvantages; one was, that the process of making the gas was intermittent, and necessarily led to fluctuations in the quality of the gas, especially in small plants. Then, again, there was the very important question, which had, to a certain extent, been referred to already, namely, that the gas which was made when the steam was cut off, which was called producer-gas, and which represented more than half of all the fuel consumed, must have a use found for it. In very many cases, however, there would not be a use for that gas as well as for the water-gas proper; but unless the two went hand-in-hand at the same place, it necessarily followed that gas must be blown off to waste, and much of the fuel lost. For these reasons he had advocated the use of an intermediate kind of gas, something between ordinary producer-gas and water-gas; and without intermittent working, he was thus able to get something like 20 per cent. of hydrogen, and not more than 48 per cent. of nitrogen. In practice he thought there was no general rule as to whether solid fuel was more economical than gaseous fuel; in some cases it was better to have the one, and in some cases the other. For instance, if they took the case of firing a steam boiler, there would be little or no saving in heating it by means of gas; on the contrary, if a low-class fuel were used, there would probably be rather more labour in removing the clinker from the gas-producer than from the boiler, if the latter were fired in the ordinary way. He had made several experiments, and had sought information in various countries, and the results all tended in the same direction. The best example that he could quote was a large mill in the north of Italy which he visited last autumn. At this mill there were twenty-two steam boilers, and four of these were Cornish boilers, fired by means of gas-producers attached to the ends of the boilers, all the appliances being of the newest kind. The technical manager informed him that these four boilers evaporated usually 7 kilos., but occasionally 7½ kilos., of water to 1 kilo. of Scotch coal. The other boilers were fired in the usual way, but with Cardiff coal, and with this, it was stated, they evaporated 10

kilos. per kilo. of fuel. The Cardiff coal cost five francs a ton more than the Scotch coal, but, allowing for this, it would be seen that there was no real saving with the gas-fired boilers. He could not himself be surprised that this was so, because he had always felt that if the incandescent mass of fuel were in the producer instead of in the boiler, there must necessarily be a considerable amount of radiant heat lost. Having taken a case favourable to the solid fuel, he would now take one where gas was essential. He referred to gas engines, which were now being made of considerable power, and as their efficiency as heat engines was known to be higher than that of steam engines, there was every probability that their use would be largely extended. These engines, of course, required gas, and here was a very profitable use for it. He could speak with the experience of engines that were developing an aggregate of about 3300 horse-power, and the general result was that, even with a small engine of about 10 horse-power, the fuel consumption was only about $1\frac{1}{8}$ lb. per indicated horse-power per hour. With larger engines it was about $1\frac{1}{4}$ lb., and at the paper-mills of Messrs. Spicer Brothers at Godalming, where there were Otto engines indicating a total of about 240 horse-power, Mr. Spicer told him, a short time since, that the average fuel consumption was only about 1 lb. per indicated horse-power per hour. He might mention, in connection with this subject, that at the Exhibition there were two engines well worth looking at; one was a four-cylinder engine of 100 horse-power, made by the Otto Company. The other engine was also for 100 horse-power, but had only one cylinder, and was the largest of its kind ever made. He had not seen it tested, so could not give its fuel consumption; but he might mention that an engine of the same type, giving 25 horse-power, consumed only $1\frac{1}{4}$ lb. per brake horse-power per hour. It was designed by Monsieur Delamarre Deboutville, and was made by Mr. Powell of Rouen. This engine would be found in the section for hydraulic machinery. Speaking generally, it might be, and doubtless was, the case, that theoretically they should expect to get a superior heating result from the solid fuel; but his contention was that in practice this was often not possible, and that for many purposes gaseous fuel was better and more economical,

especially if the best appliances were used for obtaining as high a duty as possible from the fuel.

Mr. Loomis (Hartford, Conn.) said he was from America, and as he had been largely connected with water-gas projects for a number of years, perhaps some little history of them would be interesting, and also a reference to the use of natural gas. It was stated by Sir Lowthian Bell that natural gas was costless—that a hole in the ground was bored and they got it immediately. This, of course, was rather misleading. Natural gas was confined to a small portion of Pennsylvania, in the iron region near Pittsburg, and to some parts of Ohio. In that section it was mostly controlled by large companies owning all the territory where gas could be produced; some few manufacturers were fortunate enough to hold their own. Almost all Pittsburg was supplied by such companies, who charged for the gas. In the first place, when the gas was first introduced, they supplied it at the price of raw coal, but as time went on they began to add the cost of labour, and now they had doubled the price of coal, so that all who were using gas in Pittsburg and the vicinity, or nearly all, unless they had old contracts, were paying a high price for the gas, showing that the use of gas as fuel was no saving in the matter of coal, although they did save in the matter of better production, better quality of goods, and increased output from the same amount of labour. This matter would come forward in the same way with the use of gaseous fuel. Conceding these things, they now came to the point, How could gaseous fuel be made in the cheapest and best manner, and of the cheapest material, in the place where it was wanted? Wherever it was, they must use the cheapest material to be found in that section. Large experiments had been made in America to demonstrate that point, and, of course, they found in that country that the cheapest fuel they had was bituminous coal. Anthracite coal had been used for making water-gas to a certain extent. No use had been practically made of producer-gas until lately, but taking into consideration the cost of fuel, what gas was the best for all uses, whether producer-gas, coal-gas, or water-gas? Producer-gas, to be practicable, must be produced in a

different way from what it had been in time past. It must be produced under pressure, and delivered under pressure into a holder, or with a holder-governor, or be carried about in pipes and brought to the furnace under pressure. It could then be perfectly regulated, and burnt with the air properly, as it should be. In that way producer-gas could be made to do vastly more work, as had been demonstrated by actual experiment, than could be done by the old style of passing it through a Siemens furnace with a chimney-draught. In making producer-gas, and water-gas, and coal-gas, they should be made out of the cheap, soft slack coals of the country; and, by actual demonstration of figures, they were enabled to make as many as 40,000 feet of water-gas, mixed with coal-gas, from a ton of bituminous dust coal. This gas, mixed in that way, had about 350 units of heat to the foot, which was largely in excess of water-gas made from anthracite coal, which was about 290 units. Made from bituminous coal, it had more hydrogen in it, and some marsh-gases, which increased the units of heat to that extent. The producer-gas made from soft slack coal, in properly built furnaces, was far superior to the producer-gas made from anthracite coal or coke with an up-blast furnace, and it could be made entirely free from tar—the tar could be all converted into gas, and conveyed in pipes, as he had said. They had works in America that had been running two years making producer-gas and water-gas, putting one in one holder, and the other in the other. At some large saw works in Philadelphia, the producer-gas had been passed through pipes for 1200 to 1500 feet to the heating furnace. The pipes had never been opened until a few weeks before he came away, to see if there was any deposit, and there was practically nothing found in them; there was no tar—nothing except a small amount of ash blown in from the producer, showing that producer-gas could be conveyed about and used in that manner. As to the result of using this producer-gas in heating furnaces, they found that they got certainly 25 to 30 per cent. more effective use of gas, being under pressure in an ordinary Siemens furnace, than they could when using gas made from an ordinary Siemens furnace; so that at those works they were practically making 35,000 to 40,000 feet of water-gas from a ton of slack coal,

putting that into another holder, and using it for small forgings, annealing, and tempering, and many minor applications about the works, with the result that they got as much work out of that ton of coal in a Siemens furnace—as much product as they did with a Siemens furnace direct, using the entire ton of coal. This was on account of a better way of handling and producing the gas, by working the gas under pressure.

Sir LOWTHIAN BELL: What pressure?

Mr. LOOMIS: About two inches.

Sir LOWTHIAN BELL: How was the pressure got?

Mr. LOOMIS said the gas was made with an exhauster instead of a blower; the operation was entirely reversed. Everything was taken down through the coal, and the air was passed down through the coal. The coal always being hottest at the bottom, the tar and everything else was converted into gas, and it went off with not over 50 to 55 per cent. of nitrogen, and with 40 to 45 per cent. of combustible matter. The use of water-gas for metallurgical work had greatly increased. In some large works in Massachusetts they did their entire forging with water at a saving of over 30 per cent. for labour, and nearly 50 per cent. for coal. At the Waltham Watch Works, near Boston, they were running their entire machinery with water-gas. Water-gas was passed into the works for metallurgical duties of all kinds. At the works of an important steel company, near Cincinnati, the gases were mixed together and used for drying, forging, and the like. The cost of coal had been reduced more than one-half, and the time of drying coals had been reduced from twelve hours to two hours, besides the saving in labour.

## WEDNESDAY, SEPTEMBER 25.

The proceedings of the Institute were resumed to-day—Sir James Kitson, Bart., President, again occupying the chair.

The discussion on Sir Lowthian Bell's paper was continued.

Mr. Samson Fox said that, many times in the career of the Institute, he had found himself most heartily on the side of Sir Lowthian Bell; this time it so happened that they were not on the same side of the question. No doubt they both thought they were to a considerable extent right, but he was there to lay before the Institute a few facts which had come out of the actual working of the water-gas for nearly two years. He should have been only too pleased, before the paper was written, to give Sir Lowthian Bell the full opportunity of investigating what that apparatus had been doing and what it could do, and in that case he was sure that their opinions would have been nearer agreement. Everything depended for its value upon what it could produce, and the point to which the paper was mainly directed, was to show that water-gas could not be produced at such a price as to yield any better result than that which would have been obtained from using either solid fuel or producer-gas. He did not propose to deal with the question as to whether producer-gas or solid fuel had the advantage. He would leave the point whether gaseous fuel was better than solid fuel entirely to those who had had more to do with it than he had. However, with regard to water-gas, he thought he had had a fair opportunity of knowing what could be done with it in many ways. The paper, to his mind, was considerably wrong in its statement with reference to the cost of producing the gas; and they all knew that if they got wrong as to the cost of producing to the extent that these figures appeared to be, they were sure to arrive at wrong conclusions. The author had set down 12s. 2½d. as the cost of gasifying a ton of fuel, and he also stated that, in the pamphlet to which he referred, 2s. 8d. was given as the cost

of doing the same work. No doubt there was room for dispute on that point; but he (Mr. Fox) was prepared to prove that the figures he had given were not of his own construction, but were got out by persons well able to do it, and who had every opportunity offered them for doing so. They, of course, had taken out their own costs from the actual expenditure over a period of time, in the gasifying of so many tons of fuel. The paper was also wrong in the amount put down for the cost of the fuel. The cost of the fuel in one part was said to be 13s. 5d., while in another part it was said to be 10s., per ton. They did not pay any such sum for the material they used for this purpose. The paper was also, he thought, misleading in this way, that there was some consideration taken for their saying that they used coke, and that that coke had to be produced for them. The fact was, that they used coke when somebody else had taken coal-gas off the coal that the coke was made from, and, of course, they were using a material which was very good to get hold of, and that could be bought at various prices during the year. In addition to that, in large works they had a lot of unburned or small breeze, coming from various parts of the works, and which could be used just as well as any other material for the purpose of making water-gas. Another point where he thought the figures were wrong was in the cost of steam required per ton of fuel used. It was set down at 3s. 6d., but it could not possibly be more than 6d. On these three points the paper was considerably in error—the cost of the steam, the cost of the gasifying, and the cost of the coal; and he was persuaded that they should go into the question on different lines from those which had been taken by the author. He would now come to the open-hearth question. He believed that the paper was based upon information gained from furnaces that had been working from water-gas only. Water-gas succeeded best where they had a fair mixture of the two gases, or where they had the power to mix them; where they could put in their producer-gas by a valve arrangement to any extent they chose, and where they could also mix their water-gas with a similar arrangement to any extent that was desired. There were many reasons, which there was not time to lay before the Institute, why they should not use

pure water-gas. If they did, they would at many stages of their work fall into a loss, and certainly get on towards a destruction of some parts of the furnace. He was sure the paper should have taken notice more particularly of works where a mixture of gas was used. At Leeds, they were preparing some furnaces to work on the mixed gas principle. They would have those furnaces at work in a little while, and would then see how far they were away from the results that had been obtained elsewhere. Sir Lowthian Bell spoke, as he thought, rather slightingly as to the pressure at which the gas might be used. He would give an instance why this subject had been put forward by himself. They were arranging to supply a small town with water-gas for lighting purposes. Round about this small town, but at a considerably lower point, not so high in elevation as the town, there were seven villages, at distances ranging from three to seven miles, and if water-gas could be put down at the small town, the surrounding villages were quite prepared to join in the expenditure. To do that, it would be necessary to distribute the gas from the small town to a village seven miles away; and there would be no difficulty in doing it when they knew that they had held water-gas for weeks together, and found it perfect, under 600 lbs. pressure to the square inch. There would be no difficulty in sending the gas for seven miles through a very small pipe when they could start with it at that pressure. If they did this, they could distribute it in very small pipes, having a very small gas-holder at each village, reduced to the ordinary pressure, distributing from the main centres into small gas-holders through small pipes at high pressure. That was what would be done, no doubt, in many cases. With regard to general lighting, it could, no doubt, be done better by water-gas than with ordinary gas, and very much more cheaply than by the electric light. They had used it for lighting their works for eighteen months, and were quite satisfied with the result. His own house had been lighted by water-gas for eight months, and they were quite pleased with it. There was this advantage about lighting with water-gas, that it was much purer, they did not require to consume as much atmospheric air in the room where it was burning, and in every way the advantage was in favour of the

water-gas. The great advantage came out in the cost. Where he lived, ordinary gas was 3s. 6d. per 1000 cubic feet. He could light his place for 1s. 1d. per 1000 cubic feet of water-gas, including interest and depreciation, and that had been done during the last eight months. Although much had not been said about water-gas for lighting purposes, still that was a great question, when they looked at small towns and villages, which required lighting in some fashion, seeing that they could put down an apparatus for a few hundred pounds that could work so rapidly, and make such a large amount of gas at such a low cost. Beside this, there were many other uses that they were now finding for water-gas. He believed within the next two or three months there would be at least a dozen plants at work that were now building—one or two had already started—for purposes that were never expected, and where ordinary coal-gas was either too slow in its action or not sufficiently clean, if anything could be got cleaner. They, of course, expected to realise an advantage out of this water-gas as compared with producer-gas, and there was a considerable advantage, which he put at not less than 15 per cent. Then, they knew that they would get a very much increased output in a steel furnace, and that was a great deal. They knew that they would get a decrease in the quality of the fuel required by using this particular class of generator; and he had no doubt that the wages per ton of ingots would not be so great when the plant was turning out in some cases double the amount that it turned out at present. He thought that those three conditions would be found to be of sufficient advantage to allow water-gas to proceed on its way. In conclusion, he should like to say that he wished Sir Lowthian Bell had taken his data from their own English practice; for, without wishing to depreciate what had been done elsewhere, there was no doubt that they who had started later, with ideas that had come out of the experience of others, were doing better than had been done by those who were the first to put down such plants. He should like to give Sir Lowthian, if he cared to avail himself of it, the fullest opportunity of dealing with the water-gas plant at the Leeds Forge, for the purpose of finding out how far their figures and data were correct. He had only to say that the sooner it was done the better, because this question would not stand still.

Mr. EDWARD RILEY wished to know how many of Mr. Fox's steel furnaces were at present working with water-gas?

Mr. SAMSON FOX said he had stated that they would have several furnaces at work in a very short time, which would be worked with mixed gas.

Mr. EDWARD RILEY asked if there were none working with water-gas?

Mr. SAMSON FOX said not at present; but he had given data taken from furnaces that they had worked.

Mr. EDWARD RILEY said that Mr. Fox had referred to the question of using water-gas for lighting private houses. Perhaps he would explain to the meeting how he got over the difficulty of employing in a private house so poisonous a gas as carbonic oxide, seeing that it was a gas which had no smell, whereas coal-gas had a very bad smell, but was not poisonous in the true sense of the word. An atmosphere containing 1½ or 2 per cent. of carbonic oxide was fatal to life in a very short time. Perhaps Mr. Fox would explain how he got over the difficulty that might arise from an escape of gas?

Mr. SAMSON FOX said he should be glad to do that. In the first place, it might not be generally known that the great bulk of the gas-tubing in houses was in a leaky state from end to end at the present time, and that something like 25 per cent. of the gas bill was due to leakage extant in all gas-fittings all over the country. If they made thoroughly tight gas-fittings, and introduced a little volatile liquid, that would tell the instant they had a leakage, they would then have no trouble or fear of injury arising from the use of a gas which was stated to be so poisonous.

Mr. EDWARD RILEY: What is the percentage of the carbonic oxide in the gas?

Mr. SAMSON FOX: Perhaps 45 per cent.—equal volumes, or nearly so.

Mr. Riley: It would not take much to poison the atmosphere of a room very quickly.

Mr. Fox said there was no difficulty of that kind. He had left his family for the last eight months, and he could not have done that if he had not made thoroughly sure that all his gas-fittings were tight, to begin with.

The President said this was rather irregular. Mr. Fox was not in a witness-box. If Mr. Riley had anything to say, he must speak afterwards. Mr. Fox was not under cross-examination.

M. Kupelwieser said he desired to correct two printer's errors. The cost of producer-gas should be ·18 kreutzers, not 18; and the figure 673 ought to be ·673. The coke which water-gas was made from contained about 17 per cent. of ashes and water, and 83 per cent. of carbon, and it cost about 10s. 3d. That was the average quality of coke which they had during the whole year. In the spring, when Mr. Jeans wrote to him asking him some questions, he had said that the cost was 13s., which was the price of the coke they were using at that time. The two prices mentioned by Sir Lowthian Bell were the prices referred to in two letters written at different times, and concerning a different coke. When he wrote in September, he gave the average for the whole year. They burned large coke because they could not get enough small coke. They were able at times to burn small coke and cinders, and that gave an average price of 10s. 3d. per thousand cubic metres of water-gas. The producer-gas was estimated at 3s. 1d. One thousand cubic metres of water-gas cost 6 flor. 73 kreu., or 11s. 6d.; or, per thousand cubic feet, about 4½d. The prices would not be very different from those which Sir Lowthian Bell had received from Germany. The cost of steam, 3s. per ton of coal, was not from Witkowitz, but, Sir Lowthian Bell said, from a German works. As many gentlemen seemed to be interested in the subject of water-gas, he might be permitted to give a few details which were not mentioned in the paper. The apparatus which they were using at Witkowitz was, he believed, the same as that used by Mr. Fox at Leeds. It had been working more than two years without any serious interruption, but there were

many things which ought to be known respecting it. It was not possible that the apparatus could work with coking coals. All their coals in the Moravian coal-mines were coking. He was sorry, however, that there were only some small seams that gave very good coking coal. The large output was coking coal, and that was the reason why they could not work with coal, but must work with coke. By working coal the gas always contained carbon and hydrogen, and that would not do for lighting purposes —the magnesian combes were very sensitive. If a little coal-dust got on them they would not light. Concerning the apparatus, it was found necessary to cool the parts that were most exposed to the fire. This was done by a ring filled with water; that prevented the destruction of the fire-brick at that part; but it cooled very much the mixture of slack and coke in the apparatus, so that when the apparatus had to be cleaned very much coke must be thrown out with ashes and slack. It might be that by using a purer material the results would be much better. But with their coke, containing about 15 per cent. of ashes, they must clean every three hours. He was sure that a pure, non-coking coal, like the American anthracite, would do very well, and many coals in England would also do for the same purpose. The process of making water-gas was intermittent. There was always a run of about ten, eleven, or twenty minutes in producing producer-gas, and frequently a run of three, or three and a half to four, minutes with water-gas. The production was not continuous for water-gas or producer-gas. Water-gas had to be stored up in a gasometer if they wanted a continuous supply. That was not possible with producer-gas. They produced such a large quantity, and the value of the gas was not high enough to make it worth while to have an enormous gasometer sufficient to store up the producer-gas. It was hinted in the paper, and also stated by some gentlemen in the discussion, that it was not right to use producer-gas produced by water-gas apparatus for boiler-heating; it should be used for puddling furnaces, or welding furnaces, or Siemens furnaces. But if there was only one apparatus, they had only a ten minutes' pretty large output of producer-gas, and then for four minutes there was no producer-gas at all, and that was a difficulty. If they had two apparatus, they would have twice as much producer-gas at a given time. Working with three apparatus, they could have equal

streams of producer-gas and water-gas. It was not possible, however, to arrange matters like clockwork, and to have the three apparatus going together, so that even in that case they were not sure to have a regular stream of producer-gas. That was the reason—as he worked first with one apparatus and then with two—that he could not apply it for puddling furnaces, &c., and he applied it for boiler purposes. A great proportion of the steam was used for the apparatus itself and for engine driving the blowers. The steam decomposed itself, he believed, at more than 900° Cel. They must blow the apparatus first to about 1800° Cel.; then they gave in steam; the steam cooled the apparatus very quickly, and in a few minutes, at about 900° Cel., the decomposition of the steam ceased. If they prolonged the process, they would only get the steam through the apparatus, but no water-gas would be produced. Water-gas would be much cheaper than he had stated at Witkowitz if they could take advantage of cheaper materials, such as cinders. If they used that material, they could make water-gas; but the production would be so small, and would require such a large plant to make a sufficient quantity, that he was sure they would not adopt that plan. They would soon come to the use of a good material instead of a bad one. There were, however, some cases of lighting purposes where they used very small quantities of gas—only 300 or 400 cubic metres in a day—in which the apparatus might be large enough to work with small cinders and coke, and in such cases they might produce it very cheaply. He wished also to say something about the loss of heat in producing water-gas. All the heat which was consumed by decomposing water was gained again by burning hydrogen to water; but water-gas was made by a high temperature. It left the apparatus at a heat of 1800°, and it must be cooled and purified before it came to the gasometer. All that heat was lost, and it was a large quantity. The apparatus itself was cooled with water in a very intensified way, and that was also a loss. A great part of the material, say from 6 to 10 per cent. of the coke, which had been heated to a high temperature, was removed by the cleaning apparatus. That also was a loss. By the use of a good producer, which stood near the furnace, few of those sources of loss existed. The gases were brought from a good producer as hot as possible to the furnace. There was very little cooling of the gas, and the tubes

through which the gas was conveyed were all fitted up with bricks. He believed, however, that there was great loss of heat, and that it was right that Sir Lowthian Bell should point to the fact that *the heat produced by the present roundabout way of making water-gas involved a great loss of calories.* But, as he had said previously, there were many cases, even for lighting purposes, gas-engines, and different metallurgical and chemical purposes, in which water-gas, although absolutely and relatively dearer than producer-gas, might be, and was, used with advantage.

Sir FREDERICK ABEL, C.B., said he was afraid he had very little to say that would impart additional interest to the discussion, or that might lead to any profit in his speaking. He could not, however, refrain from saying that they were very much indebted to Sir Lowthian Bell for having gone so carefully into the subject of the cost of production of water-gas, with the possible advantages attending its use; for it must be admitted that what had been elicited, in consequence, from Mr. Samson Fox comprised very valuable information, which must, indeed, be regarded as an important supplement to that which the public hitherto had received in regard to the possible extensive application of water-gas. They had learned from Mr. Fox that water-gas was not used for metallurgical purposes, as such, except under very special conditions, but that it was only employed as an adjunct, he might say, of producer-gas, or, at any rate, that the two were always used together, and Mr. Fox did not propose, or even suggest, that water-gas pure and simple should replace fuel for metallurgical purposes. Where two gentlemen so eminent as practical men as Sir Lowthian Bell and Mr. Samson Fox differed so widely in regard to the cost of production, it was, of course, very difficult indeed for a man of pure science, who dealt merely with theoretical calculations, to offer an opinion. He had not gone carefully into Sir Lowthian Bell's calculations, but they appeared to him, on the face of them, to be sound and correct. There were, however, great differences between the numerical results arrived at by him, and those which Mr. Fox deduced from practice, and there appeared also to be points that required a little rectification in regard to the data used by Sir Lowthian, as had been pointed out by the interesting remarks of

Mr. Kupelwieser, which might make some notable difference in regard to the value to be attached to some of Sir Lowthian Bell's figures. Still, it appeared to him beyond doubt that the cost of water-gas, from what they had heard, could not be taken as being so low as Mr. Samson Fox would lead them to believe. Mr. Kupelwieser's remarks, with regard to the loss of heat in dealing in actual practice with water-gas after it had been produced, were such as a practical man would give very considerable attention to in the consideration of the question whether water-gas was really, when taken by itself, or used in large proportions together with producer-gas, a more profitable way of applying fuel to general metallurgical purposes than the use of the fuel itself. Mr. Fox had pointed out that there were forms of fuel which would not be used in their ordinary condition at all profitably or easily for certain processes, but which could be used much more readily if converted into gaseous fuel. But, on the other hand, Mr. Kupelwieser had shown that there were great practical difficulties attending the use of some of these fuels of inferior description, and this, he apprehended, would be of very great importance when the question came to be considered in its practical bearings by many of the gentlemen present who desired to apply water-gas. These were important points, which must be carefully sifted before they came to the conclusion that water-gas was going to create a very great revolution in metallurgical industry. With regard to its application to lighting purposes, he conceived that practical experience had already demonstrated that, for open-air illumination, water-gas, with certain important adjuncts, might very valuably, and in some cases very economically, replace coal-gas; but he ventured to think that great caution would have to be exercised before they attempted to apply it to indoor illumination; and, although a householder, if he were an experienced gas-fitter himself, or had some gas-fitter who had been well educated up to that point, and might rely, by excellence of workmanship, upon excluding from his rooms the poisonous carbonic oxide, which was contained to the extent of about 50 per cent. in water-gas, yet he ventured to doubt whether, at the present time, or for some long time to come, they could place such reliance upon the necessary radical improvement in the work of the gas-fitter, as to render it at all a safe thing to propose to

use water-gas generally, even in very carefully overhauled gas-fittings, as a substitute for coal-gas. They ought to thank Sir Lowthian Bell most heartily for the care and pains that he had taken to go into this subject impartially. He knew personally that, some years ago, Sir Lowthian Bell had a special reason for going most carefully and impartially into the question of the application of water-gas to various purposes, and into the possibility of applying it economically in connection with metallurgic work; and the Council had felt, therefore, much indebted to Sir Lowthian when he consented to give the Institute the benefit of his special knowledge and his sound judgment. Water-gas, as they all knew, was no stranger; in fact, it was a very old friend, and, to his knowledge, it had come to the front over and over again during the last twenty-five years, at the very least. In conclusion, he would say that if Sir Lowthian Bell accepted the very candid, and, he might add, generous proposal of Mr. Samson Fox, to look thoroughly into the data, based upon the achievements at Leeds, he had no doubt that they would have put before them, by the time they next met, a thoroughly reliable statement as to the *pros* and *cons* connected with the production and practical value of water-gas.

The PRESIDENT said he was afraid they must bring this very interesting discussion to a close, seeing that they had so much business before them. But, as England had had its innings, he thought it was only right that they should hear something from their French friends, and he proposed to ask Mr. Alex. Pourcel, who had some experiences to give as representing France, and Mr. Frederick Siemens, to whom the regenerative furnace owed so much, to say a few words as representative of Germany, and he would then call upon Sir Lowthian Bell to reply.

Mr. FREDERICK SIEMENS said he had only a few remarks to make. He had no intention of entering into the discussion, as he had not had the advantage of hearing Sir Lowthian Bell's paper read. The point that struck him in the discussion was, that Mr. Samson Fox said he did not use water-gas alone for furnace purposes, but used it mixed with producer-gas. That practice would quite agree with his (Mr. Siemens') experience in using

gases. It might be added, however, that he did not see any advantage in making two gases separately to be afterwards mixed. He had had a great deal of experience for a long period with various kinds of gases, using them in furnaces with which he had been experimenting, and he came to the conclusion that it would be desirable to divide them into two classes, luminous gases and non-luminous gases. Non-luminous gases he found to be of very little service for furnace purposes, though they were very useful when used for heating by contact. For instance, with the incandescent gas light they must use non-luminous gases; for in that case the flame struck the material which had to give light, and heated it to a high degree by contact. This method of applying flame was out of the question for use with large furnaces, which are mainly worked by radiation from flame. Non-luminous gas did not radiate light, neither did it radiate heat; therefore they could not possibly heat a large furnace with non-luminous gas, and it was to the class of non-luminous gases that water-gas belonged. They were recommended to use it mixed with producer-gas made from coal, or carburetted in some other way so as to make it fit for use in large furnaces. It was rather a complicated matter to mix gases. Mr. Kupelwieser stated that water-gas, being made by an intermittent process, ceased occasionally altogether. It would, therefore, have to be stored up in gasometers, and there was a difficulty in mixing it with producer-gas, because the one gas was produced under pressure and intermittently, and the other without pressure and continuously. He should be glad to know how the gases were mixed, for if they could be easily mixed, he thought the result would be very good. According to his experience, water-gas, being non-luminous, could never be used alone for large furnaces, because the luminosity of the gas was of the utmost importance for heating purposes in large chambers. He had had occasion to read a paper a few years previously before the Institute upon heating furnaces exclusively by radiation from flames, and such furnaces could never be worked with water-gas; but if it was mixed, for instance, with illuminating gas, as proposed by Mr. Fox, then, of course, it might act very well.

Mr. Alex. Pourcel remarked that it had been stated that water-gas was not a stranger, but an old friend. For many

years, indeed, water-gas had been manufactured, but until now a practical application had not been attained. In 1872 he witnessed, in the north of France, experiments made by Mr. Tessié du Mottay. These experiments were duly reported in the *Comptes-rendus des Ingénieurs Civils* (*Transactions of the Civil Engineers of France*). Again, quite recently, before a meeting of civil engineers, the question of water-gas had been discussed under all its aspects, from the hygienic point of view, in that of the production of calorific agents, and in that of the production of sources of light. He would remind them that, at the outset, when experimenters wanted to make water-gas, they could not use coal. Therefore, he did not quite understand Mr. Wildy, when he stated that coal, coke-waste, and, in fact, all inferior fuels, could be indifferently used. But if they used coal, they must choose a dry and pure coal, as, if they used coke, it must be of a very pure quality; and, in that respect, he entirely concurred with the views of their friend Mr. Kupelwieser, who asserted on the previous day, "When you state that you use waste coke, I answer that I had to choose the best qualities of coke which I could find to make water-gas." Eighteen years ago water-gas was partially applied, and in order to obtain practical results, it was necessary, in 1872, at a time when coke was very dear in France, to buy it at 50 francs (£2) per ton to make water-gas. He was well aware that at that time their experience was limited to experiments, whilst to-day the object pursued was metallurgical applications, for which the gas was also used mixed with carbonic oxide. But, as had just been stated by Mr. Kupelwieser, inferior fuels might also be used; only, for the same production of gas, complicated apparatus were required, and, ultimately, the cost price was increased. With regard to the communication made by Sir Lowthian Bell, he believed it to be very admirable, as it possessed an unexceptionable quality, the eloquence of figures. It was quite true that every one was at liberty to interpret figures as he deemed proper. Mr. Wildy discussed them with a certain acrimony, and a vivacity which he himself should possibly have displayed, had he been called upon to defend his own interest. This was understood, but he thought it was difficult to convince one's opponents by bringing more or less vivacity into the discussion; it was experience alone which must support and finally

establish facts. In his opinion, a long time would elapse before water-gas would be applied from a practical point of view. He did not condemn water-gas; far from it. It had its importance, and found an application in certain works—the welding of corrugated boiler flues, for instance. It was the same in pure chemistry when a gas evolving a high number of calories was required, the oxy-hydrogen blow-pipe was used. But the gas was dear; and, however it might be used in chemical works, this he could assert, as he employed these processes almost daily, ordinary gas and air were mostly employed. What was done in pure chemistry by substituting tight apparatus for the use of hydrogen gas could also be done in industry. But he believed that, for a long time to come, no practical or economical application of water-gas could take place.

Sir LOWTHIAN BELL, in reply, said he was almost afraid to attempt to meet all the objections raised to the paper he had placed before the Institute. With regard to what fell from Mr. Head, the difference between them amounted to this—that if Mr. Head were going to put up a simple re-heating furnace, he would not use the regenerator furnace; but if he had a regenerator furnace, he would continue its use. In order to compress the paper just read, he omitted to state that the furnaces erected in place of the Siemens for re-heating purposes were provided with boilers, which, in his opinion, where steam power was required, was the most economical way of using the waste heat from ordinary reverberatory furnaces. This, of course, did not interfere with the legitimate use of the regenerative furnace where intensity of temperature was required. With regard to Mr. Wildy's remarks, his friend Mr. Pourcel had spoken of the vivacious way in which he had referred to some of his (Sir Lowthian Bell's) remarks, and he was rather sorry to note one or two words to which he did not wish to attach undue importance, because he knew, unhappily, from personal experience, that words sometimes slipped off one's tongue which afterwards were regretted. Mr. Wildy spoke of his (Sir L. Bell) having mentioned something on the ground that "the wish was father to the thought." Now, the object of such discussions as the present was to get at the truth, and it was in no other spirit that he approached the question before them. He was quite sure

that Mr. Fox was actuated by the same spirit, and that his manner upon the platform would satisfy anybody that he had said nothing which he did not himself entirely and honestly believe. They were met, if they could, to interpret the laws of nature. He had made broad statements, setting forth, if he could, what was the scientific aspect of the problem before them. If he was wrong, his character in this capacity ran some danger of being wrecked by his bringing forward statements which could not be properly substantiated. They had heard the explanation of Sir Frederick Abel, whose ability to speak upon such questions was not to be doubted. If, then, there was any fallacy in the statements made by Mr. Fox upon different occasions, he thought Mr. Fox would admit that the sooner such errors were corrected the better for himself and for all concerned. Mr. Wildy and Mr. Fox had expressed some surprise that he did not keep nearer home in order to obtain the data upon which his paper was founded. Mr. Fox would remember that, something like five weeks ago, he (Sir L. Bell) wrote to ascertain if he could have any information on the subject of water-gas. Probably owing to other engagements, Mr. Fox was unable to furnish this. He did not mention this in the language of complaint, but gave it simply as a matter of fact, to account for his having been dependent, in the first instance, on Mr. Kupelwieser's data. With regard to the information obtained from Germany, it was the result of an application by Mr. Jeans, who, totally unknown to himself, had written to Mr. Kupelwieser, in order to obtain such data as he thought might be useful to any one who undertook to discharge the duties which he had endeavoured to fulfil. If there was any error, by overstating the price of coal or coke employed, he was astonished that this should constitute a charge against him, because, if water-gas was a cheaper form of fuel than solid coal, surely the dearer they were paying for solid fuel, the more important it was to use the combustible matter in the manner that Messrs. Fox and Wildy were recommending. In the translation sent to him by Mr. Jeans, the fuel used at Witkowitz for making water-gas was mentioned as coal, whereas in point of fact it was coke, and it was only on applying to Mr. Kupelwieser direct that that error was made known to him. Therefore, he could not agree that he had taken, to use Mr. Wildy's own words, any unwarrantable liberty in the statements made use of. He dealt with the question

under the supposition that it was coke which was used; but when he heard that coal was employed, he examined the question under this change of circumstances, and he had given the results. It was, however, entirely beside the question, from a scientific point of view, whether coal or coke was employed. It was very well to talk about his exaggerating costs, which he had done upon the authority of the gentleman to whom they had just listened, and who spoke upon large personal experience, but it must not be forgotten that cost of production was not the only or the principal question before them. It was rather the scientific aspect of the case they were considering. Could they, or could they not, use coal more beneficially, from a calorific point of view, in the form of gas or in the form of coal? Professor Abel mentioned that the subject was not a novel one, and, so far from any wish he might entertain being father to his thought, he would remind Mr. Wildy that his firm were large consumers of coal, and his wishes naturally led him to promote any object tending to secure economy of fuel. But, independently of that, he might mention that, some six years ago, he was in Germany, and hearing of this water-gas, he proceeded to examine it. He went to Frankfurt, and saw an experimental water-gas apparatus there. He was impressed with its simplicity, and he believed then, and continued to believe, that there were some cases in which water-gas might be profitably employed. So far he agreed with Mr. Fox. He afterwards went to Essen, in order to see the welding of the corrugated flues of Mr. Fox, and he was struck with the admirable way in which the work was performed. But when Mr. Fox claimed a complete abandonment of all solid fuel, with a view to introducing it in the form of gas, then he dissented from any such view. Mr. Wildy had spoken, not, he thought, very clearly, of the blast-furnace. He had said that their blast-furnaces were merely makers of producer-gas, and in the pamphlet written by Mr. Fox it was mentioned that blast-furnace gas perfectly resembled producer-gas. It did no such thing. About one-third of the carbon in the gas from a blast-furnace was converted into dioxide, which constituted a limit to the power of oxidising the carbon gas in smelting iron. It was an entire mistake to suppose that there was any identity between the two kinds of gas. Producer and

water gases were, or ought to be, free from carbon dioxide, which was not the case with blast-furnace gas. Some exception had been taken to the construction which had been put upon Mr. Fox's speech in regard to the size of the pipes required to convey water-gas for illuminating purposes. It was true that, in a speech made some months ago, Mr. Fox used the word "compression," but he never for a moment imagined that it could occur to any one to compress this gas so that a $1\frac{1}{4}$-inch pipe could carry as large a volume of it as a 36-inch pipe could do of ordinary coal-gas. For this it was estimated that a pressure of 600 lbs. on the square inch would be required. Surely Mr. Fox must have overlooked the power which would be required, the high temperature which would be generated, and the leakage of a very deadly gas under such a condition of things as those imagined by him. With regard to making cheap gas from gas-maker's breeze, where was the breeze to come from, after all the gasworks were suppressed, in order to make way for water-gas? Indeed, even now, as the President had just stated, breeze at Leeds, when washed, sold for 9s. a ton. Mr. Fox had called him to account for the estimated cost of converting solid into gaseous fuel. He had himself doubted the accuracy of the statement, which was Mr. Kupelwieser's, and not his; and, until Mr. Kupelwieser had explained the matter, he was in very great doubt as to whether it could cost anything like 12s. $2\frac{1}{2}$d. to gasify a ton of coke in the manner proposed. But supposing it did not, Mr. Fox had himself given 2s. $8\frac{1}{2}$d. per ton for doing the work; and as coal in ordinary times sold for 5s. per ton at the pit, that meant an addition of 50 per cent. to the price of coal. He could assure Mr. Fox that all that he wanted was to ascertain the simple truth. He believed, in the interests of that gentleman himself, the earlier this was ascertained the better. This observation was equally applicable to those who might contemplate laying out large sums of money in erecting plant which, in the end, might not realise the expectations formed of it. Mr. Kupelwieser had spoken with evident sincerity on the subject, and though he might not agree on every point with himself (Sir Lowthian Bell), on the whole there was a general agreement in the views expressed by both. He should be happy to avail himself of the offer made by Mr. Fox; and if he had erred in any of

his assertions, he would, at the earliest period, admit the mistake into which he had fallen.

The PRESIDENT said the members would agree that the discussion had been a most useful one, and that they were indebted to Sir Lowthian Bell for having written the paper, was evidenced by the great interest which had been taken in the subject, not only by the members of the Institute, but by the world at large. Great hopes and anticipations had been held out by those who had so energetically taken up the question of the development of the application of water-gas, not only for iron and steel purposes, but for general purposes. They had learned, at any rate, that water-gas was admitted to have its advantages for special purposes. They had learned from their American friends that it was used extensively for welding purposes, and for heating portions of steel for forging. So far they had gained some knowledge. It was, he thought, admitted that Mr. Fox had met this question in a very open way, seeing that he had offered to place his experiences at the service of the Institute, and to examination by so eminent a scientific man as Sir Lowthian Bell. It was quite clear that the subject would come up for further discussion, and he would content himself by moving a vote of thanks to Sir Lowthian Bell, who had rendered great service to the Institute by the way in which he had introduced this subject.

A vote of thanks was then given by acclamation to Sir Lowthian Bell for his paper.

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## CORRESPONDENCE.

DR. GEORGE LUNGE (Zürich) remarks that for some considerable time past he had given much attention to the question of gaseous fuel, and more especially to water-gas. He had been, therefore, much interested in the paper on that subject emanating from the high authority of Sir Lowthian Bell, and as he had been requested to say something on this matter, he would give a short abstract of the opinions he had formed thereon.

For common heating purposes, especially for comparatively low temperatures, and in cases where the process in question

admitted of a good utilisation of the heat evolved, the direct use of coal, coke, &c., was to be preferred to any form of gaseous fuel, excepting, of course, a gift of nature, like natural gas. This applied to such cases as the raising of steam, the evaporation of solutions, and so on, where the operation was carried on at a temperature not much above 100° C.; but it applied also to certain high temperature operations, such as the smelting of ores in blast furnaces, the burning of bricks and lime in Hoffman kilns, and the like, where the gases, after doing their proper work, were made to yield up a great portion of their surplus heat in a preliminary heating of the materials introduced into the process. Where this was not the case, but where, on the contrary, the chimney-gases left the apparatus at a high temperature (say 400° C. and upwards), the use of producer-gas was frequently preferable to the direct use of coal, for two principal reasons:—Firstly, because gaseous fuel permitted more easily than solid fuel the introduction of the principle of "recuperation," and therewith the attainment of high temperatures; secondly, because gaseous fuel could be burned with but little above the theoretically necessary quantity of oxygen, which means that a much smaller quantity of chimney-gases was produced, and much less sensible heat was carried away by those gases than when burning coal on ordinary fire-grates. It was not at all difficult to burn producer-gas in such a way that the chimney-gases contained 19 per cent. by volume of carbon dioxide, whilst it could not be called bad work if the chimney-gases from ordinary fires contained half as much $CO_2$; but in the latter case, twice as much chimney-gas was produced from a given unit of fuel than in the former, and twice as much heat was lost in this way. This told all the more, the higher the temperature of the exit gases, and this might make it more economical to convert the solid fuel first into producer-gas, and then to burn it directly. This was more especially the case where the heat, generated by the reaction $C + O = CO$, was not lost by allowing the producer-gas to cool down in long pipes or flues, but where the producers were directly attached to the furnaces, in which case hardly more loss by radiation was incurred than in the passage of ordinary fire-gases from the grate of a reverberatory furnace over the fire-bridge. In such cases it was obviously

unfair to deduct from the heating value of the fuel that portion which had been evolved in the reaction, $C + O = CO$, for nearly all of this heat (amounting to 30 per cent. of the total heating value of carbon) was still present in the producer-gas when it arrived at the place where it was burned into $CO_2$.

The question whether gas-producers were better worked with or without the introduction of steam was only a secondary one, as long as the proportion of water in the former case did not exceed that which could be used up without lowering the temperature of the producer below the point where a continuous system of working was possible; to this class belonged the Dowson, the Wilson, and the Schilling producer, and others, which he had classed together in his writings as "semi-water gas-producers." Although the gas yielded by them contained from 10 to 15 per cent. of hydrogen, and was decidedly richer in combustible constituents than ordinary "Siemens gas," it still belonged to the same class as the latter, and could not be classed with coal-gas, except for the driving of gas-engines and the like. But the case was quite different when the amount of steam introduced into the producer was so large that the reaction, $C + H_2O = CO + H_2$, was carried out to its full extent. This, as has been pointed out by Sir Lowthian Bell, necessitated a discontinuous system of working, an alternation between "blowing hot" and "blowing cold," in order to supply the extraneous heat absorbed in the just-mentioned endothermic reaction. This alternation of work produces, on the one hand, a very rich gas, the "water-gas" proper, and, on the other hand, about four times as much by volume of a somewhat poor producer-gas. The water-gas proper possessed about half the heating power of coal-gas, and had an advantage over this in point of cheapness, and by burning with a smokeless flame of such small size that its temperature is much higher than that of a coal-gas flame, even when employing a Bunsen burner. Unfortunately, water-gas, which contains about 40 per cent. of carbon monoxide, is consequently from five to eight times as poisonous as coal-gas; but for technical purposes this was much less important than for the question of distributing such gas in service-pipes for dwelling-houses; and for some manufacturing operations, the intense heat given off by the water-gas flame possessed a special value, no

other mode of heating being equal to it in this particular. But, unfortunately, considerably less than one-half of the total heating power of the fuel was recovered in the shape of water-gas; much more of that heating power was locked up in the producer-gas made in "blowing hot," a gas whose full utilisation was decidedly difficult, and which had been hitherto allowed to go to waste in all those cases where water-gas was made for illuminating purposes.

There was a great deal more to be said on those matters, but he would only refer to his various papers on that subject, namely, in *Chemische Industrie*, 1887, pp. 170–179; *Zeitschrift für angewandte Chemie*, 1888, pp. 462–465, and pp. 667–668, which papers had been noticed in some English periodicals as well. He had proved that, even by theory, a loss of heating power was involved in the manufacture of water-gas, owing to the fact that the water was introduced into the process as a liquid, and left it (in the chimney-gases) in the state of vapour. Partly from this, partly from other reasons, he felt bound to raise his voice against the exaggerations representing water-gas as "the fuel of the future," and to give it as his opinion that water-gas would be very useful for certain purposes, but would always retain the character of a speciality, and would certainly not supplant the direct burning of coal, nor producer-gas, nor even coal-gas. The advocates of water-gas had not liked this at all, and some of them may have privately abused him, but they had never even attempted to refute his views. Still, when, soon after, a glowing account was published of the results obtained with water-gas in the manufacture of open-hearth steel at the Witkowitz works, it would doubtless appear to many onlookers that there must be, after all, rather more in that matter than he and some others had thought; the "ounce of fact" would, no doubt, be made to do its old-established duty against the "pound of theory." At all events, for processes carried on at a temperature similar to that required in the steelmaking process, the economy of water-gas over other modes of firing seemed to be clearly demonstrated. But at Witkowitz they had found, as had been done previously, times out of number, that some processeswhich for a few months or so seemed to work in the most beautiful and economical manner, in the long-run exhibited so many drawbacks that "all the shine was taken out of them." That

had been clearly brought to light by the authentic information supplied to Sir Lowthian Bell by Mr. Kupelwieser, and in that light they must read the expectations based upon the calculations of Mr. von Langer.

He refrained from entering in detail upon the interesting statements and figures contained in Sir Lowthian Bell's paper. In some few instances he should have preferred putting the case in a little different way; but this mattered all the less, as he was glad to find that, in a general way, the valuation put upon water-gas by that eminent scientist entirely agreed with the opinions he had previously published, and of which he had just given a short abstract. Utterly disinterested as he was in this question, either one way or another, he did not feel entitled, when asked about his opinion, in the public interest, to refrain from pronouncing against the exaggerated statements put forth in some quarters as to the value of water-gas, and the probability of its becoming "the fuel of the future."

Mr. WATSON SMITH remarks that Sir Lowthian Bell, in his paper, appeared to treat of the comparative fuel-values of coal, producer-gas, and water-gas *plus* its producer-gas; and he showed that, for each 100 units of the three kinds of fuel burnt, there was afforded by coal, 83·93; producer-gas, 71·14; and water-gas, with its producer-gas, 78·80. According to this view, however, it would appear that, whilst Sir Lowthian Bell admitted the possible value of water-gas in special cases where, for instance, an intense temperature is required in order to do work quickly, he must have omitted to take other conditions involving valuable return, or at all events compensative value, into account. By using inferior species of coal, or other fuel of nitrogenous kind, it is possible, by means of proper adjustment, to obtain, in addition to a producer water-gas, a certain amount of tar-oils of high calorific value, and ammonium sulphate. This had been demonstrated by Ludwig Mond, in his address to the Society of Chemical Industry (*Journal Soc. Chem. Ind.*, 1889, p. 508). It might be urged that this is very well for an alkali-maker, but quite another thing for an ironmaster or other fuel consumer. But Mr. Mond simply took the market value of sulphate of ammonia; and as to tar-oils, these are of as little moment outside fuel-value to him as to any

other consumer of fuel. He thus obtained from every $31\frac{1}{4}$ tons of coal treated in the producers 1 ton of sulphate of ammonia, worth £12. However, $6\frac{1}{4}$ tons of coal were consumed in working up this sulphate, and, adding other expenses, a total cost of, say, £5 was obtained to set against the gain of £12, leaving nearly £7 profit on the sulphate. The tar-oils obtained Mond also utilised as fuel, and found that, though only obtaining 3 per cent. on the fuel gasified, yet those oils possess double the evaporative power of coal. The efficiency is thus brought up to 80 per cent. of that realised from the same fuel by hand-firing. At the price of 6s. per ton of coal, the profit on the sulphate, about £7, would represent about $\frac{140\text{s.} \times 20 \text{ cwt.}}{6\text{s.}}$, or 23 tons of coal. He ought to add that an allowance for wear and tear of plant was still necessary. Thus the depreciation of efficiency as against hand-firing was rather more than compensated for in the values of tar-oils and ammonia realised. If the gases were used hot from the generators, tar-oils and ammonia must be sacrificed. It should be added that, in hand-firing, of course all the nitrogen is lost, and carbon is lost in the ashes to some extent. One-half the nitrogen is gained by the process described by Mond, and the ashes only contained $3\frac{1}{2}$ per cent of carbon. But these considerations, though they were in the broadest sense indispensable, were still strictly supplementary to one of fuel-value; and Sir Lowthian Bell's conclusions were not one whit the less valuable for being strictly confined to a rigid comparison of the three fuel-materials on the basis of strict calorific efficiency. It may be of service and useful suggestiveness thus to touch upon another side of the question, and to regard its bearing upon the general subject. He thought, in the main, it could not be urged that Sir Lowthian Bell's assumption, that, in the production of producer- and water-gases, these gases were received at the regenerators *after being cooled*, was, comparatively speaking, an assumption wide of the mark, inasmuch as, in such cases, the gases usually passed, in the first instance, into and through rectangular flues composed of wrought boiler-plate; at all events through iron flues, exposed to the air, and hence to radiation and atmospheric cooling.* These flues

* In many cases it is not convenient, if possible, to annex producers so close to the furnaces that the gas shall be used hot.

have to be conveniently arranged for the purpose of readily removing soot and tarry matters, which might under some conditions, and during certain possible hitches, in the production deposit somewhat largely. Hence usually these gases were very considerably cooled, and may be considered as generally delivered not much more than warm. But though Mr. Mond's experiments and results were referred to, yet it must be confessed that at present, and in many cases, both sooty and tarry matters were simply removed from the flues, and not utilised in the efficient manner Mond recommends. If, then, besides loss of heat by atmospheric cooling in the flues, we have loss of calorific value through accumulations in the flues, the ground and basis for Sir Lowthian Bell's calculations, for the most part, remain supported. Mr. Smith regarded it as perfectly incredible that 20 to 25 per cent. of the illuminating gas registered as used in our houses was to be classed as leakage; for coal-gas has its *natural* smell, somewhat various in different towns, but always distinct enough to the nostrils. In the odourising of water-gas, what innocuous substance with smell bad enough, and yet sufficiently cheap, could be used? Also, how many lives might be lost before the new odour was positively associated with gas, and nothing else in common use by the public? That coal-gas had its natural and well-known odour was a great safeguard for the public, as, also, that it could not be deprived (economically) of that odour. In adding an odour, *first*, expense must be undertaken in the provision of a material, and in its somewhat uniform distribution; and, *second*, certain risks to life and health, through a chance cessation of supply of the odouriser, or through a possible change of odour, &c. Thus, at present, though the gas manufacturer be a monopolist, he could only hurt them by supplying foul gas. With a water-gas monopoly, however, they had a far more poisonous gas than coal-gas to deal with. It was naturally odourless; it might be odourised, or it might not; or again, the odour might be changed; and in all these cases (under the disposal of the commercial speculator) grave risks to the health and life of the public were presented.

C. R. Alder Wright, D.Sc., F.R.S., remarks that the calculations given by Sir Lowthian Bell led to the conclusion that on burning a given quantity of coal (*a*) in an ordinary furnace where

the chimney-gases escape at 427° C; (*b*) by means of a gas-producer without steam, chimney-gases escaping at 377° C; and (*c*) in a water-gas plant, chimney-gases again escaping at 377° C, the quantities of heat lost as sensible heat in the chimney-gases were, respectively, 16·07, 16·61, and 11·05 per cent. of the heat actually generated by the complete combustion of the coal; whilst, owing to further loss of heat by cooling the gaseous fuel in the two latter instances, the total amounts of heat lost in the three cases, became, respectively 16·07, 28·86, and 21·20 per cent., thus indicating that a coal-fired furnace was perceptibly more economical than a similar one fed with the gases generated from the same amount of coal in a water-gas plant; and that this, again, was notably less wasteful of heat than it would be if an ordinary gas-producer were used instead of water-gas plant.

This latter result, however, was based on the assumption that the gases generated in the two last cases *do not carry any sensible heat into the furnace;* obviously this would be the case when gaseous fuel was manufactured with the object of supplying a town, &c., with gas for heating purposes; but where producer-gas was made for manufacturing purposes on the spot, it was used *hot* as it came from the producer; and the same remark applied to water-gas when similarly employed, as no real necessity existed to chill the gas and condense any small quantity of undecomposed steam admixed therewith. A small proportion of the sensible heat contained in the heated gases would inevitably be lost by cooling during the transference of the gases from the producer to the furnace where it is burnt; but otherwise, *absolutely the same amount of heat must be actually developed and delivered into the furnace in all three cases,* so far as the combustion of the coal was concerned. In the case of the water-gas, somewhat more heat is actually brought in, viz., that contained in the steam as blown into the producer. If, thus, the chimney-gases escaped from a coal-fired furnace at a higher temperature than from one fed with gas-producer gas (427° as against 377°, in the cases examined by Sir Lowthian Bell), it must follow that *more heat was actually utilised in the latter case than in the former,* the extra amount utilised being the difference between the quantities of heat in the chimney-gases in the two cases, less the amount of heat lost by cooling during the passage of the producer-gas to the furnace:

this was, of course, supposing the combustion to be equally perfect in each case. In just the same way, if the chimney-gases from a furnace fired with the producer-gas and water-gas, alternately generated in a water-gas plant, escaped at the same temperature as those from another furnace fired with ordinary producer-gas (377° in each case), *the latter would utilise somewhat more heat than the former*; because the chimney-gases from the water-gas furnace would be the same as those from the other furnace, so far as the products of combustion of coal were concerned; but would, in addition, contain an admixture of steam at 377°, which would obviously carry away more heat than was introduced by its means when it was blown in at a temperature not greatly above 100°. This was, of course, on the supposition that the loss of heat by cooling during transference from producer to furnace was the same in each case. Hence it resulted, from this mode of viewing the matter, that if the heat lost by cooling the gases during their passage to the furnace be left out of consideration, *a gas producer-fired furnace was the most economical of the three, instead of the least*; it utilised more heat than the coal-fired furnace, because the chimney-gases by supposition escaped at a lower temperature; and more than the water-gas furnace, because the chimney-gases in this case, although at the same temperature by supposition, carried away more heat in the admixed steam.

This reasoning was based on the obvious fact, that exactly the same total amount of heat will be generated by conversion of a given quantity of materials into certain definite products, no matter what may be the nature of the intervening stages passed through in the transformation. Thus a given quantity of carbon directly burnt to carbon dioxide will generate a certain amount of heat. Neither more nor less will be produced if the carbonbe first converted into carbon oxide (as in the ordinary gas-producer), and this subsequently burnt to carbon dioxide; whilst exactly the same heat evolution will be again obtained if the carbon be first converted into water-gas by the action of steam, and the resulting mixture of hydrogen and carbon oxide then burnt so as to reproduce the steam and form carbon dioxide. In the first case, the chemical changes are expressed by the equation,

$$C + 2\,O = CO_2;$$

in the second, by the two equations,

$$C + O = CO$$
$$CO + O = CO_2;$$

and in the third, by the three equations,

$$C + H_2O = CO + H_2$$
$$H_2 + O = H_2O$$
$$CO + O = CO_2;$$

but in each can the net result as to chemical change is identical, and the net heat development during that change is identical also.

If, instead of carbon, coal be employed, exactly the same end result would be attained in each case, any combustible matter present (other than carbon) producing the same amount of heat, no matter which way it be burnt, provided the combustion ultimately produced the same end products.

Although furnaces fired with water-gas did not possess any advantage over those fed with ordinary producer-gas, in the way of burning fuel so as to give rise to a larger development of heat on the whole, they nevertheless could be so worked as to produce a result impossible to attain with producer-gas. Suppose that a furnace is heated by gas regularly supplied by an ordinary producer so as to attain an approximately constant temperature. If, now, the producer be worked as a water-gas plant by alternately injecting air and steam, instead of blowing in air only, and if the rate of coal consumption be supposed to remain the same as before, the effect on the temperature of the furnace would be alternately to raise it above, and depress it below, the constant temperature previously attained. During the period when steam was blown in and water-gas produced, a hotter flame resulted from the formation of hydrogen; this extra heat, for the time being, was obtained at the expense of the sensible heat of the hot carbon in the producer, which was cooled owing to the absorption of heat during the change,

$$H_2O + C = H_2 + CO_2.$$

Later on, when air was blown in instead of steam, the producer-gas now formed was at a lower average temperature than it would have possessed had the mass of carbon not been cooled during

the production of water-gas in the previous stage. Hence the furnace temperature fluctuated. Whilst water-gas was being made and burnt, it was hotter than it would be if fed with gas from an ordinary producer; and during the next stage, whilst ordinary producer-gas was being made and burnt, the heating effect was less, because this gas entered the furnace at a lower temperature. The surplus heat developed during the one stage exactly balanced the deficiency during the other stage.

Now, suppose that, instead of heating the same furnace alternately with cooler producer-gas, and with water-gas capable of generating a hotter flame, the arrangements were so carried out that a continuous supply of water-gas was led into one furnace from a series of producers worked regularly in succession, so as to develop water-gas, whilst the ordinary producer-gas found in the series during the intervals was separately burnt elsewhere. Obviously, the water-gas fed furnace would attain a considerably higher temperature than it could reach were it fed with ordinary producer-gas; whilst a proportionate diminution in the temperature of the furnaces, &c., fired with the cooler producer-gas would result. The practical effect of thus making water-gas and producer-gas alternately by injecting steam at regular intervals instead of air would consequently be that a portion of the heating power of the hot producer-gas would be sacrificed, and a corresponding increase in the heating-power of the water-gas obtained, enabling a greatly exalted temperature to be reached in one portion of the entire plant, at the expense of a somewhat lowered temperature in the rest of the plant.

It is easy to see, as Sir Lowthian Bell had pointed out, that, for certain special purposes, the possibility of thus attaining higher temperatures without any great expenditure of capital in costly plant may be highly valuable; but, except in such special cases, the use of water-gas rather than producer-gas for ordinary manufacturing purposes did not appear to have any particular advantage counterbalancing the higher cost of production.

An entirely different conclusion, however, resulted on comparing water-gas and producer-gas from the point of view of a supply of cheap heating gas for household purposes, working gas-engines in small factories, and such-like objects. In this case, the sensible heat of the gases as they left the producers was

entirely wasted (excepting in so far as it may be partly utilised for steam raising, evaporation, &c.), and cool gas supplied to the consumers through street mains, and pipes, &c. For every 12 parts by weight of carbon converted into carbon oxide, 2 parts of hydrogen were obtained in the water-gas plant, but none at all in ordinary producers (leaving out of sight hydrogen and hydrocarbons resulting from the volatile part of the coal, which would be the same for each). Taking Sir Lowthian Bell's heat values (2400 as the heat of combustion of carbon oxide to carbon dioxide, and 29,400 as that of hydrogen to *aqueous vapour*), it followed that, with the ordinary gas-producer, 12 parts of carbon would form 28 parts of carbon monoxide, developing on combustion $28 \times 2400 = 67{,}200$ heat units; whilst with the water-gas plant they could develop the same amount of carbon oxide, and, in addition, 2 parts of hydrogen, giving rise to $2 \times 29{,}400 = 58{,}800$ heat units more; i.e., *an increment of* 87·5 *per cent., or about* $\frac{7}{8}$, *in the heating-power of the gases obtainable from a given weight of carbon was occasioned by converting it into water-gas instead of producer-gas.* This increment was, of course, obtained at the expense of the sensible heat of the original hot gases; but as this heat was virtually wasted, the practical result was, that the heating-power of the gases obtained was nearly doubled, at little other cost than that of the steam blown in. If the gases be compared volume for volume, a yet greater increment resulted: producer-gas contained about $\frac{1}{3}$ its volume of combustible gas, and $\frac{2}{3}$ inert nitrogen; the quantity of carbon that would give 100 volumes of producer-gas containing 33·3 of carbon oxide would consequently yield 66·7 of water-gas containing 33·3 volumes carbon oxide, and 33·3 hydrogen; *i.e.*, 2 volumes of water-gas would result, instead of 3 of producer-gas. Hence, the heating-power of water-gas as compared with producer-gas, volume for volume, would be $\frac{3}{2} \times 187{\cdot}5 = 281{\cdot}25$ per cent., or *nearly three times as great.* On account of the greater calorific power of the gas, and of the absence of inert nitrogen therefrom, the temperature of a water-gas flame was considerably hotter than that of a producer-gas flame; so that the former may be employed as a source of light in various forms of incandescent gas-lamps (*e.g.*, the Welsbach), for which purpose the latter was quite unsuited. Further, in order to develop a given quantity of heat, nearly three times the volume of producer-

gas must be burnt that would be required of water-gas, so that a producer-gas installation for the supply of cheap heating-gas for domestic purposes, &c., would require gasometers and mains, &c., of some three times the size of those requisite for a water-gas installation of equal heating-power.

It is worth noticing in this connection, that, for precisely the same reasons that water-gas was preferable to producer-gas for household heating purposes and such-like modes of employment, it was inferior to ordinary coal-gas; *i.e.*, to any kind of gas (produced by destructive distillation or otherwise) consisting mainly of hydrogen mixed with hydrocarbons, more especially marsh-gas. The heats of combustion of *equal volumes* of hydrogen, marsh-gas, olefiant-gas, and carbon oxide were in the proportion of the following figures (the hydrogen present being supposed to be burnt to liquid water in the first three cases):—

| | |
|---|---|
| Hydrogen | 68,500 |
| Marsh-gas | 210,000 |
| Olefiant-gas | 334,000 |
| Carbon oxide | 67,200 |

So that ordinary coal-gas containing 45 to 50 per cent. by volume of hydrogen, 35 to 40 of marsh-gas, 6 to 8 of carbon oxide, and a few per cents. of more complex hydrocarbons (usually expressed as equivalent to so much olefiant-gas), would have a relative calorific value of 130,000 to 140,000 on this scale, volume for volume—*i.e.*, since water-gas would have a value of about 68,000, and producer-gas of about 23,000, *such coal-gas would possess about twice the calorific value of water-gas, volume for volume, and six times as much as producer-gas.* With coal-gas containing more hydrocarbons, the superiority would be still greater. The inference from this would seem to be that, as long as inferior coal, shale, waste vegetable or animal matter, petroleum residues, and similar substances, giving rise to gaseous hydrocarbons by destructive distillation, were obtainable, the gases thence produced were likely to be preferable to water-gas for domestic heating purposes, just as water-gas was preferable to producer-gas for this class of uses.

Apart from calorific value, there was one very strong objection to the household use of water-gas or mixtures of water-gas and producer-gas, viz., the intensely poisonous character of carbon

oxide. Ordinary coal-gas, containing 6 or 7 per cent. of that gas, was very dangerous on this score when even a small leak occurred, especially in a bedroom. In this case the peculiar odour of the gas usually gave some degree of warning that an escape existed. With comparatively scentless water-gas, containing several times as high a percentage of this deleterious constituent, the danger of poisoning would be greatly intensified.

Admitting that this objection was practically not of serious moment, there still remained another difficulty in the supply of water-gas for household purposes, &c.; viz., that, in order to produce it, something like three times as much carbon must be converted into producer-gas as was used for the water-gas, so that, as about 3 volumes of producer-gas contained as much carbon as 2 of water-gas, from four to five times as much producer-gas would necessarily be made, measured by volume, as was manufactured of water-gas. Hence, either the production of water-gas for town supply must be coupled with some other branch of industry in which this large quantity of producer-gas could be utilised, or else the producer-gas must be more or less wasted, and the cost of the water-gas correspondingly increased.

Sir LOWTHIAN BELL has replied on the correspondence as follows:—At the Paris meeting of the Institute, where I had the honour of reading a paper on gaseous fuel, I pointed out some of the objections, in a calorific point of view, to water-gas as a substitute for coal, &c., in the solid form. Objections were strongly urged by gentlemen who differed from the views I had submitted for the consideration of those present. Our Secretary afterwards suggested the propriety of inviting opinions from certain chemists familiar with the practical use of coal and other varieties of fuel. Accordingly, Mr. Watson Smith, Professor Lunge, and Dr. C. R. Alder Wright have kindly replied to Mr. Jeans' request, and the result appears in the present volume. These have been sent to me, and I have been asked for a reply, should any be necessary. I should have preferred waiting until I had visited Mr. Fox's works, but as the opinions of these gentlemen virtually confirm my figures, I shall at once answer the minor objections they raise to what I said in my paper.

Mr. Watson Smith calls attention to my having omitted in

my calculations any mention of the ammonia which, by converting coal into gaseous fuel, might be collected and converted into the sulphate of this alkali, worth £12 per ton. My arguments throughout were of a comparative nature, and if the necessary apparatus were added to the plant intended for the production of water-gas, there is no reason why it should not also be employed when the ordinary producer-gas might be used as a substitute for solid fuel. So far, however, as the actual manufacture of water-gas and its accompanying producer-gas, up to this time, is concerned, the question of condensation of ammonia has not arisen, for the simple reason that hitherto coke, and not coal, has been employed in the processes recommended by Mr. Samson Fox.

Mr. Watson Smith cannot be said to agree entirely with the opinions expressed by Professor Lunge and Dr. Wright in respect to my omitting, in the case of the water-gas manufacture, any credit for the heat evolved while gasifying the solid fuel, amounting, as Professor Lunge observes, to 30 per cent. of the total heating value of carbon. In order to apply the two gases—water and producer—to the numerous uses claimed by the water-gas companies, both will have to be distributed through separate pipes over a large area. Thus, whether they are cooled or not at the works, they cannot arrive at the point of consumption until the heat they contained on leaving the apparatus has, in a great measure, disappeared. This view of the position seems to have been that held by Mr. Fox himself, certainly as regards the water-gas proper, for he passes it "through a porous mass in a scrubber on which a spray of water constantly falls" on its way to a gas-holder, where it is to be stored;* and when the accompanying producer-gas has to be distributed for consumption, Mr. Fox speaks of it also being collected, if necessary, in a gas-holder. There are, moreover, obvious difficulties and dangers connected with the conveyance of highly-heated gases through a system of pipes, which I need not enlarge upon.

Of course, I cannot but admit the justice of Dr. Wright's assertion that, if the gases are delivered to the point of combustion, with all the sensible heat they contain, credit must be taken for its amount. In an open-hearth steelwork there is no difficulty in so arranging the ordinary producers, as now em-

* "Description of Water-Gas Plant," pp. 12 and 16.

ployed, and furnaces in such close proximity, that the gas from the former reaches the latter with only a moderate loss of its heat. But it is not improbable that much difficulty would attend such an application of the water-gas system. It is clear, to keep up a continuous supply of either gas, that at least three generators will be required. This estimate is based on Mr. Fox's own figures, which give twice as much time devoted to the generation of producer-gas as that occupied in making the water-gas. To obtain 400 cubic feet of water-gas, say, 2400 cubic feet to include producer-gas, he says a space of 250 square feet is required. Now, it is not uncommon for a steel furnace to consume 200,000 cubic feet of gas per hour. Thus, after making due allowance for so large a quantity being obtained in a relatively less space than in the apparatus described by Mr. Fox for his 2400 cubic feet, no one conversant with the subject will question the difficulty of so arranging, around a steel furnace, the necessary water-gas plant, as to deliver its product to the steelmaker without a considerable loss of the sensible heat. In like manner, I agree, and I say so, in Dr. Wright's statement as regards the chimney-gases, viz., that more heat is utilised in the combustion of water-gas and its accompanying producer-gas than in burning coal or ordinary producer-gas—the loss in the latter two being 16 or 17 per cent. of the whole, against 11 per cent. in the former. I also agree with Dr. Wright in there being a certain amount of heat brought into the producer by the steam employed when making water-gas. This, however, I would suggest, is the reverse of an economy, because the steam has been raised by the fuel burnt under the boiler where it was generated, at a considerable loss of its heating power.

Dr. Wright's concluding statement, in respect to sensible heat being utilised in decomposing the steam in a water-gas producer, does not admit of contradiction. It appears to me, however, that *all* the sensible heat cannot, from the nature of the operation, be so utilised. This operation, as I understand, is thus conducted. After the water-gas proper has been generated by passing steam *downwards* through the hot contents of the generator, and these have been so cooled that there is a risk of producing carbon dioxide, instead of carbonic oxide, the steam is shut off. Air is then introduced at the *bottom* of the producer, by which the carbon becomes, near the tuyeres, intensely heated, gradually

decreasing in intensity as the producer gas, thus generated, reaches the point of escape at the top. Such heat—and there will be some—as is carried off with this gas, unless utilised at once, must be so much wasted. This, however, is not, I imagine, the chief source of loss; for when the steam is admitted at the top, for want of the proper temperature, some carbon dioxide will there be formed, which, however, is converted into the monoxide when it reaches the more highly heated carbon lower down. This must take place at first at some distance from the bottom of the generator, otherwise the formation of water-gas would speedily cease; because, according to Mr. Fox, a temperature of 1000° C. is required for the complete conversion of carbon and steam into water-gas. Admitting the correctness of this hypothesis, there will ensue a minimum loss of 5·6 per cent. of the heating power of the gas, and it may easily be twice this, all of which is lost when the water-gas passes through the scrubber and is stored in the gas-holder.

The object of the argument in my paper was, in the main, in the words of Dr. Wright, to show that "a given quantity of carbon directly burnt to carbon dioxide will generate a certain amount of heat; whilst exactly the same heat evolution will again be obtained if the carbon be first converted into water-gas by the action of steam, and the resulting mixture of hydrogen and carbon oxide then burnt so as to reproduce the steam and form carbon dioxide." So much for the calorific section of the question, and when we turn to the commercial we have to consider the cost of converting the solid fuel into a gas. Into this I need not again enter, for Mr. Kupelwieser, who has had ample experience in the application of water-gas, completely disposed at Paris of what may be expected in that direction.

I repeat once more that, for certain uses, water-gas may have a great value; at the same time, the profitable disposal of the producer-gas, containing 75 per cent. of the carbon used, may often prove an inconvenience. It may be that the occasions in which a more expensive fuel than solid coal, as these gases recommended by Mr. Fox undoubtedly are, may be more numerous than I am at present disposed to believe. In this matter I hope to obtain some interesting information from him when he is prepared to receive me at his works, as he kindly offered to do at our discussion in Paris.

# THE THOMSON ELECTRIC WELDING PROCESS.

By Mr. W. C. FISH, Boston, Mass., U.S.A.

Several years ago, at least in the history of the application of electricity to the arts, Professor Elihu Thomson, of Lynn, America, had occasion to deliver a lecture before the Franklin Institute in Philadelphia. In preparing certain electrical apparata for this lecture, Professor Thomson had the questionable misfortune of short-circuiting an induction coil, which, quite naturally, resulted in the fusion of the copper wire of the coil. If fusion could thus be produced accidentally, and if economical and practical, why should it not be intentionally produced and applied to the treatment of metals? And from this accident probably came the germ of thought which, to-day, extending and developing itself, gives to the arts the process of electric welding. During some time this idea lay dormant in the mind of Professor Thomson, who was busily engaged in the development of the Thomson-Houston system for electric lighting and transmission of power; but finally experimental machines were constructed, and these conclusively showed the excellence of the electric weld. The Thomson process was first publicly exhibited in New York in 1887, and since that time the development has been rapid in America, where it is recognised, more and more each day, as among the growing and important applications of electric energy.

The physical principles underlying this process are probably elementary to many of the audience, and have frequently been described in the technical journals.

The experimental law relating to the production of heat in a circuit through which an electric current flows, states that heat is produced at every portion of the circuit, first in direct proportion to the electrical resistance at any given point of the circuit, and secondly, in proportion to the square of the current strength. The resistance varies with the nature of the metal, the temperature, and inversely as the area of cross-section. Therefore, if an

unclosed circuit of inappreciable resistance be completed by the insertion and abutment of short lengths of the pieces to be welded, the passage of an electric current through the circuit will produce a transformation of electric into heat energy, and the production of this heat will take place almost entirely at the point of abutment of the metal pieces where the cross-section of the conductor is virtually of least area, and the resistance is proportionately great. If the current is of sufficient strength, a welding heat is produced at the point of abutment, and with the aid of suitable pressure, forcing together the heated extremities of the pieces, a weld may be made. The localisation of the heat is still further assisted by the increase in the resistance of metals which takes place with increase of temperature, and thus the primary production of heat at the point of the weld, tends, in itself, to the accumulation of heat at that point.

From this same reason—the increase of resistance with increase of temperature—the current tends to flow uniformly through the cross-section of the weld, since, if one portion should become cooler than another, an increased flow of current through this portion would occur, its temperature and resistance would be raised, and the uniformity of flow of current would be restored. Several automatic arrangements have been kindly furnished by Dame Nature.

The requisites of an electric welding plant, generally speaking, are:—

1. Apparatus for the production of a suitable current, with means for quickly and exactly regulating the current. The current for welding may be either continuous or alternating in direction. The employment of the alternating current offers certain electrical advantages in the production of a sufficient current strength, and in the transmission of energy to a distance from the source of supply, and is that usually employed.

2. Clamps which shall hold the pieces to be welded in correct relative position, and which shall be relatively movable in such a manner that the pieces may be forced together during the operation of welding.

3. A method for permitting the welding current to enter the pieces without loss of energy. This is usually accomplished by causing the movable clamps which hold the pieces to become

a portion of the circuit, and, from their ample contact, both with the pieces and the remainder of the circuit, to offer no appreciable resistance to the current flow.

4. A manner of obtaining a suitable pressure which shall force the pieces together during the operation of welding.

The last three considerations relate chiefly to simple mechanical details, and are easily obtained.

With our present knowledge relating to the transfer of heat energy into electric energy, a welding current, that is, one of great volume, is best produced by the three following methods:—

1. The employment of secondary or storage batteries. This method is scarcely comparable with the two which follow, though it might be used to advantage in certain special cases and particularly where the existing steam plant is of insufficient power. In this case, energy could be stored in the batteries, and drawn upon when sufficient is accumulated.

2. A dynamo of extremely low armature resistance furnishes current directly to the weld. The weld, however, must be near to the dynamo, else, unless cumbersome and expensive leads be employed, the loss of energy in the conduction of the current would be excessive. In practice, the clamps carrying the pieces to be welded are placed directly above the dynamo on a suitable table. This system is simple and economical, but necessitates the carrying of the "work" to the dynamo.

3. The employment of an alternating current dynamo and a transformer. The function of the transformer is to transform, through the medium of a magnetic circuit, the comparatively high electric pressure and small current produced by the dynamo into a current of comparatively great volume, but of low pressure, which current shall be applied to the weld. Since, by this system, we can carry the small current produced by the dynamo to any desired spot with little loss of energy, and through conductors of small cross-sectional area, and there obtain a current of the desired magnitude, this method is the most flexible and useful of the three.

Placing our dynamo near any suitable source of mechanical energy, the welding may be done at a distance of a mile or more, if need be. The circuit of the transformer in which the heavy welding current is produced, usually consists of a single turn of

heavy copper bar, terminating in the movable clamps which carry the pieces to be welded.

In repetition, but only in reference to the usual case, the electric weld is accomplished by abutting and clamping the pieces to be welded in such a manner that they complete an electric circuit, and are, to a greater or less extent, depending upon each particular case, included in this circuit; then, upon the flow of a current of sufficient volume through this circuit, the point of abutment is brought to a welding heat, and the pieces, while hot, are forced together by a suitable pressure. The different fluxes employed in the electric process are similar to those used in the ordinary methods of welding and brazing. The pieces in some cases are slightly rounded at the ends before welding, both to increase the localisation of heat, and to ensure the thorough fluxing of the metal, and the expulsion from the weld, upon the application of pressure, of whatever combinations of the flux and metal, and other impurities, may be present.

In addition to the ordinary method of determining the welding heat—namely, the colour of the metal—the operator of the welding process is also guided by the resistance to compression which the heated pieces exert when subjected to pressure. With a well-known grade of steel, for example, one might make the weld with eyes closed, relying entirely for the determination of the welding heat upon the "feeling" of the metal when under pressure.

The pressure applied generally produces at the weld an enlarged cross-sectional area. Through different combinations of heat and pressure, this enlargement is somewhat under the control of the operator, and with those metals, such as iron and steel, which are not "hot-short," can be reduced by hammering while the pieces are hot. Judicious hammering at the weld, particularly with the harder grades of cast steel, is often advantageous on account of its refining tendency. The fibre of wrought iron can also be restored by hammering, though, as a rule, the continuity of the fibre is but little impaired through welding.

Some metals, such as copper and brass, weld at a temperature nearly equal to that of fusion, and have also a very limited range of temperature within which the weld can be made. In welding metals of this nature, the tension of a spring may be nicely adjusted to produce the necessary pressure, to give the desired

approach of the pieces at exactly the proper temperature, and this done, to automatically shut off the current from the weld.

Another advantageous result of the simultaneous application of pressure and heat, is the slightly greater permissible range of temperature within which the weld can be made, and the consequent decrease of danger of burning the metal. Thus the welding temperature of certain classes of steel can be slightly reduced below that ascribed to the given metal in the smithy, by the substitution of pressure for temperature.

The following figures, taken at random, give a few results of tests made on the tensile strength of welds:—

| Material. | Breaking Strength per square inch. | Position of Fracture. |
|---|---|---|
| | lbs. | |
| Wrought iron | 53,110 | 17 inches from weld. |
| Cast steel | 81,000 | At weld. |
| Bessemer steel | 59,580 | " " |
| Copper (hard drawn) | 31,830 | " " |
| " " " | 32,480 | ¾ inches from weld. |
| Brass | 40,820 | At weld. |
| " | 47,730 | ¾ inches from weld. |
| Steel and German-silver | 40,410 | At weld. |
| Cast steel and wrought iron | 52,130 | 3 inches from weld in the iron. |
| Brass and wrought iron | 33,550 | At weld. |

Generally speaking, in the welding of the ordinary commercial metals, after the characteristics of the metal and the knowledge of the requirements for its welding, have been gained by experimenting, a tensile strength, at the weld, of 90 per cent. of the strength of the unwelded metal is obtainable.

The time of welding varies with the conditions under which the weld is made. Thus, but only within limits, a comparatively large expenditure of electric energy for a short time is equivalent, for welding, to a smaller expenditure of energy during a longer time. The quicker the weld is made, however, the more economical it is, since there is less time for the loss of energy through the conduction and radiation of heat.

Determinations of the power and time required for welding give somewhat empirical results, owing to the indeterminable effects of conduction and radiation of heat, and other factors more or less changeable with different sizes and metals. For

the same reasons, no general definite statement can be given of the required current density per square inch.

From many tests upon the time and current required for welding iron of varying sizes, mention may be made of the following approximate figures, which are also closely applicable to steel:—

| Ampères per square inch required. | Time of Weld. | Product. |
|---|---|---|
| 9,500 | 40 seconds | 380,000 |
| 12,000 | 30 „ | 360,000 |
| 15,000 | 20 „ | 300,000 |

The power required per square inch of material in the last case, for example, the material being round iron of one-half inch in diameter, is the product of 15,000 and 1·16 (the number of units of electrical pressure or volts in the welding circuit), giving 17,400 volt-ampères, the equivalent of 23·3 H.P. Assuming the efficiency of the electrical apparata to be 85 per cent., we obtain 27·4 H.P. as that to be applied to the belt of the dynamo. The actual power required for the half-inch bar itself is, if we keep our same imagined efficiency of electrical apparata, 5·38 H.P.

Without desiring to introduce questions of a purely commercial value, for which this is neither the time nor place, a rough summation of its claimed advantages, and of its different classes of applications, may both be of interest, and expose more fully the nature of this welding process.

1. The ability to unite most commercial and precious metals and alloys; also several combinations of different metals and alloys. Most of these substances have hitherto been unweldable by other processes, chiefly owing to the inability to nicely regulate the supply of heat to the weld, and to the impurities existing in the forge fire and other commercial sources of heat. The criterion for welding certain metallic substances is unknown, though this may well be from lack of sufficient experimenting. Aluminium is doubtless a weldable metal, and has been electrically welded; still, the knowledge of its proper treatment is not complete. Some grades of alloys resist welding on account of their extremely brittle condition when heated.

2. The simple commercial advantages of economy, rapidity of work, &c. The consumption of energy takes place only during the brief period of the operation. Moreover, the process

can be used in those places where a forge fire would be a source of annoyance or danger.

3. The nicety and certainty of the work is obtained chiefly through the cleanliness of the heat employed, and also because the pieces to be welded are held in correct relative position during the entire operation; thereby many irregular shapes can be welded, which, to the smith, offer inconveniences in manipulation.

The localisation of the heat, besides the economical advantage, prevents any annealing action except in the immediate vicinity of the weld.

4. The operator of the welding machine needs no knowledge of electrical laws, nor need skilled labour be employed. Besides, since the welding current is of extremely low pressure, there is absolutely none of the danger which many, on seeing the tremendous heating effect of the current, have supposed to exist.

The various applications exist in many of the mechanical arts. The following is an incomplete mention of a few which at once present themselves to the mind:—

I. The welding of solid material. This general statement includes all wire welding, whether the construction of long lengths in the process of wire manufacture, or the making and repair of joints in the various mechanical and electrical industries. In this connection may be mentioned the welding of wire ropes and cables. That this is possible without considèrable loss in the continuity of the individual wires composing the cable may be surprising, but, in reality, a tensile strength at the weld of upwards of 80 per cent. of that of the cable itself is obtainable, while the flexibility is practically unimpaired. A solid collar placed around the weld prevents the deformation of the cable during the operation.

This class of work also includes the welding of all sorts of solid bars, angle iron, &c., as well as the lengthening of connecting rods, rails, shafting, and constructive materials in general.

Another important application is the welding of tires, hoops, bands, and similar endless work. In work of this nature, it might be expected, at first thought, that the greater portion of the current would flow through that solid and continuous branch of

the ring which did not contain the point of weld, since the continuity of the metal is somewhat broken at this point, and the electrical resistance is increased. Nevertheless, either by suitable clamping arrangements, or by electrical devices, the current may be forced to flow almost exclusively through the proper path.

In this category of solid bar welding would be included the welding of links of various sizes and different metals, both commercial and precious. The ordinary form of link is generally made by placing two "U" shaped pieces end to end, the two welds occurring in each link being simultaneously made.

Doubtless a considerable range of work will be found in the treatment of the precious metals, the welding of rings, and other ornamental devices. Both gold and silver, as well as platinum, have the property of acquiring under heat a condition perfectly suitable for welding.

2. Pipe work, including the welding and brazing of various metal pipes, either into long lengths and coils, or even, as is now being done in America, for the utilisation of what would otherwise be "scrap." By proper shaping of the pipe ends previously to the welding, the cross-section of the pipe at the weld will remain practically unchanged. One chief requirement for pipe welding is that the entrance of the current into the pipe shall take place with sufficient uniformity around the circumference.

3. General construction and repair work. The application to tool-making and repairing might be particularly mentioned, and the substitution, when desirable, of soft grades of steel and iron in place of harder and more expensive cast steel. When two different grades of steel are united, the higher carbonised metal apparently gives up some of its carbon, at the point of weld, to the less carbonised metal, and thereby tends to produce an uniform graduation of the metal from one piece to the other. In welding two alloys, such as brass and German-silver, there seems to be simply a mechanical mixture of the two, but no tendency to form a third alloy.

4. The applications of electric heating for shaping, forging, brazing, local tempering, and annealing, exist in many industries: for example, the heating of pieces to be pressed into shape while hot in the clamps, straightening bent shafting and bars, or the formation of local and accurate bends.

It may be of interest to mention the possibility of electric riveting, which has already been accomplished, and is found to be a perfectly practicable process. The cold rivet is placed in the rivet-hole, electrically heated to the proper temperature, and then headed. The heating of a half-inch rivet, of two or three inches in length, would occupy probably about twenty or thirty seconds. As the plate itself becomes somewhat heated in the immediate vicinity of the rivet-hole, there is a partial weld made between the rivet-head and the plate.

This paper, though incompletely describing the fundamental principles of the art of electric welding, and scantily touching upon a few details of possible interest, gives but little idea of the questions of scientific interest which arise in the treatment of metals by electricity, or of the different uses to which the process either has been, or can be, applied. As an apology, the writer can only express the desire that any discussion which may follow will bring up those points which will lead to an increase of our knowledge of the various conditions and phenomena of heated metals, and their necessary treatment.

## *DISCUSSION.*

Mr. Alexander Siemens said Mr. Fish had very kindly shown him privately the process of welding by electricity. He could only say that he saw a bar of about $\frac{1}{4}$ or $\frac{3}{8}$ diameter welded perfectly in a short time. Besides that, he was in a position to confirm the general results; for in making one of the Atlantic cables about ten years ago, the idea occurred to his firm that welding by electricity might be quicker for the sheathing wires than the ordinary welding. An electrical machine was, therefore, arranged alongside one of their cable machines, and all the joints for the sheathing wires were welded by electricity. Of course, for their purposes, it was of the greatest importance that the tensile strength should not be materially less in the joints than in the body of the wire. They made very careful experiments, and also found the same results in efficiency as mentioned by the author—that the weld was nearly as strong as the wire itself, and certainly, on the average, stronger than one of the ordinary welds. He thought the members would find that this subject was mentioned by Sir William Siemens in one of his addresses. If they saw for themselves the ease with which electrical welds were made, and the very perfect results that followed, he was quite sure they would agree with Mr. Fish, who predicted a very great future for this process.

Mr. W. C. Fish said that, in relation to the copper-wire welding, he was told on the previous day of a series of tests made with copper-wire in which the welds averaged 90 per cent. of the original strength of the metal. That was 90 per cent. as they came from the welding machine; but, in other tests, upon the passage of the copper-wire through the rolling-mill, this strength was increased up to about 97 per cent., so that there was an increase of, at any rate, 2 or 3 per cent. by the passage of the copper through the mill.

A Member said it would be interesting to know whether copper or brass tubes could be welded to iron or steel tubes.

Mr. D. ADAMSON said that, personally, he was exceedingly interested in the paper, and was very much obliged to Mr. Fish for bringing the subject forward, and for his liberal offer to show his machines at work in Paris, as well as to give members an opportunity of seeing them on their visit to America next year. It was a matter of great personal interest to himself, seeing that he welded about 1000 feet of plate work every week in a regular, orderly manner, and a few hundred feet in a very irregular manner. However, before adopting the process, he should thoroughly examine the matter personally, as had been suggested, and consider whether the power required was or was not more than was commensurate with any economy that might be developed by its practice. For instance, if it required 27·4 horse-power to weld a half-inch square bar, as he often required to weld 20 square inches, it would be necessary to have something like 550 horse-power to get *pro rata* the force to accomplish that purpose. That seemed to be a force so enormous that it would be difficult to get a remunerative operation. Had this invention been published, say, forty years ago, before the steel tire became a great commercial business, solidly rolled, it would have been of the most vital importance to ensure the welding of tires and such-like work. In his early practice, they used to weld railway tires in the same way as that described by the author in welding small sections of bars; that was, by heating them in a furnace, using a right and left hand screw, screwing them up until they developed a much larger sectional area, and then bringing the weld to the anvil, and reducing it by hammering to a close approximation to the regular section. This process had evidently one great advantage in not needing to have preparation. In ordinary welding with the hammer, they were obliged to increase the sectional area, so that, when the two pieces were brought into contact, the weld might be effected by reduction. As they all knew, that was the common practice. If this process of welding were adopted, and the two pieces brought into contact in a small sectional area, then, as local fusion set in, and compression developed the weld, the purpose would be accomplished without preliminary preparation. Where, however, they had large sections to deal with, such as welding a plate $\frac{1}{2}$ inch in thickness and 40 inches in length, which would be 20 square inches in section, it would be very difficult to bring sufficient compressive force

to get the work done, unless they had a tremendous expenditure of power to accomplish the purpose. From the few experiments he had had the pleasure of witnessing at the Glasgow Exhibition, it appeared that the welding of copper and the alloys of copper, say, the higher incorporated bronzes, or even those that contained an enormous lot of zinc, might be easily accomplished, which certainly could not have been carried out by any other process. There would also be great advantage, looking at it from his point of view, in handling the harder classes of steel. The welding of the higher alloyed irons had not often caused much anxiety simply at the weld, but the difficulty was the jar when the temperature passed away down to a colour heat, say, at 3, 5, 7, or 10 inches from the point of highest temperature; and as the hammer was used to accomplish the weld, the metal broke down at this cooler temperature, and failure was the result. In the electric weld, where the intense heat was confined to such a very limited area, there was no likelihood of high alloyed irons breaking down at some distance from the weld. That would be an enormous advantage; in the case of tools, welding operations could be accomplished which could not have been done previously. He could see, also, that it might be applied to breakages, because, without removing the parts from the position they occupied, they might bring the electric current, and weld the shaft that had broken down, for instance, in a cotton mill, which was a thing that often came before him, a shaft frequently showing an abrupt break; and in such a case, if they could bring the two ends in contact, make the weld, and keep the shaft in position, they would be accomplishing a great deal. Although their discussions were usually of a scientific, and not of a commercial character, they would have to look at the subject from its commercial aspect before adopting this plan for large sections. They had, nevertheless, sufficient evidence before them that for small sections it was exceedingly advantageous, and certainly for welding refractory metals it gave them a power which they did not before possess, and were not likely to obtain by the old processes of fire-welding. For these facilities the author of the process deserved their warmest commendation.

Mr. Ewing Matheson said he had taken some trouble to

investigate this matter of electric welding. Mr. Fish was kind enough to give him very full explanations in London; and he had also seen some of the welding done at Glasgow, and at the Paris Exhibition he had had some "best Yorkshire" iron of his own welded, and he was taking it back to England to test. It appeared, from the engineering point of view, that the system would be most useful for large repetition work, where the number of articles to be welded would repay the cost, which must be considerable, of the clamps and special apparatus for holding and directing the pieces to be welded. He could not himself see that it could ever replace ordinary smith's work for occasional or miscellaneous welding, but for such purposes as welding angle-iron frames, or other articles which required costly labour and took considerable time, the system offered very great advantages indeed. Mr. Adamson had mentioned the welding of plates. He (Mr. Matheson) understood, from those gentlemen who had machines at work, that they had not yet succeeded in welding any width greater than three inches, and therefore it was not yet available for welding plates, or boiler rings, which no doubt would be a great boon to many of them. With regard to the power required, he thought they should take into account that the welding process occupied only from twenty to forty seconds, and, no doubt, a small engine with a heavy fly-wheel might concentrate for the few moments wanted a sufficient power. On the other hand, he thought the margin of power given between the electric horse-power and the mechanical horse-power was not sufficient. He did not think that any one accustomed to electrical machines would venture to have a 100 horse-power steam-engine if he wanted 85 electrical horse-power. He must have a greater margin than that, although in that matter they were open to correction by electricians. One other point which appeared to be rather astonishing was, that wires, when welded, should give, as he understood, 85 per cent. of the strength of the wire. A wire got so much of its strength from having been drawn, that it was very difficult to see how a weld could transmit more than the strength of the original wire rod. In other words, if a steel rod which would take 30 tons to the inch was drawn, and became wire which would carry 100 tons to the inch, one would have thought that the weld would only have transmitted the strength

of the 30-ton wire rod, and not the strength given to the wire by drawing. These were all points which would have to be investigated before the system became a commercial success, but that it would become a commercial success for certain purposes, he thought, was undeniable.

Mr. CHARLES WOOD asked whether any experiments had been made in welding cast iron, or in welding together broken castings? There were many cases in which, if they could succeed in joining two castings, or two pieces of castings, it would be of the utmost value; such, for instance, as machine frames where there was a large amount of fitting, and where repair could not be effected, or a light column.

Mr. W. C. FISH, in reply, said that Mr. Adamson had referred to the power required. He (Mr. Fish) probably did not make his statement in a sufficiently clear manner. Mr. Adamson had spoken of 27·4 horse-power for a half-inch bar, whereas he (Mr. Fish) had given 5·3 for a half-inch bar; 27·4 was for the inch bar, and that was a very liberal estimate indeed. In reference to the question of plate work, they had not welded on this side of the water pieces broader than 3 inches, because they had had no occasion to do so, and had not the machines to do it without special clamping arrangements. A boiler-plate or a plate weld in general could be accomplished in two ways, either by welding a whole section at one time, or by operating so as to weld piece by piece along the seam. In order to bring that system to a successful issue they would have to experiment for a few weeks at least, and they had not had occasion to do it yet. He believed it was being done in America now. Of course, it did not pay to prophesy a commercial success until it had been done, but he saw no reason why it should not be done. Mr. Adamson also spoke of the pressure that would have to be applied in a plate, for instance, 40 inches long, and half-an-inch thick. If that plate was iron, the pressure would not be very great, and a one-man power would suffice for providing it. If it were steel, particularly of the harder grades, the pressure would be considerable, and in those cases he might suggest the use of a hydraulic press, or possibly something in the way of

a lap weld, with rollers to shut the weld down, the rollers acting upon each individual portion. Then, speaking of the welding of the higher classes of steel, he thought it was a very important application, in some respects; and he believed that every grade of steel, except some of the newer grades, like silicon steel, had been welded. He had welded commercial steel perfectly, but manganese steel he had only had occasion to try two or three times, and he did not succeed in welding it nicely. Since then, he had seen a man who had welded it, and who told him that the secret of welding manganese steel, which was true also of Mushet steel, was not to be afraid of giving too much heat. They could not burn the steel very easily, but these steels would not take much pressure when warm. In respect of the injuries from the effects of heating at some distance from the weld—the rotting effects of heat—he had noticed that slightly in particular grades; but they had not the same trouble that the smith had, because the action was so quick. Mr. Matheson spoke of large repetition work. Naturally the application of the process would prove particularly simple and advantageous in cases of special and repetition work; nevertheless, with a single machine nearly every form of work could be welded, by employing clamps fitted with interchangeable "dogs," suitable for each particular form of metal to be welded. Of course, the process would replace a portion of the smith's work, and would increase the range of his work. Reference had been made to the strength of weld of a drawn wire rod. A wire rod, in being drawn, possibly might have received some tempering effect, and in comparing the strength of the weld with the strength of the rod, they must not compare the strength of the weld with the rod as given them to weld, but must take a piece of wire and anneal it, and compare the strength of the weld with the thoroughly annealed wire. Mr. Wood had asked about the welding of cast iron. Cast iron was perfectly weldable.

The PRESIDENT moved, that the best thanks of the meeting be given to Mr. Fish for his most interesting paper. Of course, developments of this process occurred to them all. They could see, as engineers, what an enormous value it would have if they were able to weld finished work without destruction, and, of course, the welding of boilers by the welding of rivets *in situ* would be

an enormous gain. The members would be interested to know that a cable message had been received that morning from the Thomson Electrical Welding Company, inviting them to visit their works in Massachusetts next year. He hoped that the members would be able to accompany him on that visit.

A vote of thanks having been passed to Mr. Fish by acclamation, the following paper was read :—

# ON ALLOYS OF IRON AND SILICON.

By R. A. HADFIELD, Sheffield.

The alloying of elements, other than carbon, with iron is a comparatively new field, and possesses special interest, not only to those concerned and engaged in the treatment of metals, but also to those who study the physical properties of substances. As the properties and nature of alloys of carbon and iron are fairly well understood, it is hardly necessary to consider them here, and in order to narrow down the considerations dealt with in this paper to a practicable limit, attention will be confined solely to alloys or mixtures of which metallic iron and silicon form the principal constituents.

An investigation of the properties of manganese steel, *i.e.*, an alloy of iron and manganese, was placed before this Institute by the author some twelve months ago, and its physical properties have been fairly well determined, as compared with alloys of iron with other elements. This was the more practicable owing to the fact that the manufacture of "cast iron" alloys of manganese, that is, ferro-manganese, had been for some time past in a very advanced state. In other words, the cheap production of the alloys known as rich ferro-manganese—a material containing 80 per cent. of manganese and 5 per cent. to 7 per cent. of carbon, the residue being iron—has enabled experiments to be readily carried out by further alloying such rich manganese products with pure iron.

Mr. Turner's paper read at the British Association Meeting, Bath, last year, described experiments with steel containing from ·10 per cent. to ·50 per cent. of silicon, and the details were fully given in the "Proceedings" of the Institute. The writer was asked by Mr. Turner and the British Association Committee to investigate the effect of higher percentages of silicon, and he thought that the results of his inquiries might also be of interest to the Institute.

The subject of alloys of iron and silicon has for some years occupied the writer's attention, but it was not until lately that rich cast iron alloys of silicon, *i.e.*, ferro-silicon, have been obtainable, and even now they cannot compare in richness of silicon with that of the manganese in ferro-manganese. The highest ferro-silicon yet made contains not more than about 18 per cent. to 20 per cent. of silicon. Fortunately, however, owing to the peculiar fact, noticed more fully further on, of its lowness in carbon, this is much better fitted for experimental work, as compared with, say, 20 per cent. ferro-manganese. Such a percentage of silicon, though comparatively speaking not so high, is sufficient to enable a suitable experimental material to be made, *i.e.*, a resultant material not containing too much carbon to interfere with an examination of the effect of the metalloid silicon upon the metal iron. Thus, while in the case of rich spiegel or ferro-manganese the carbon present amounts to some 5 or 6 per cent., the 20 per cent. ferro-silicon, on the contrary, contains comparatively little carbon—always under $1\frac{1}{2}$ per cent. and often under $\frac{3}{4}$ per cent.—so that by means of this cast iron alloy, when further diluted or mixed with pure iron, the malleable material or steel produced practically contains but little carbon. The curious fact that ferro-silicon alloys, as they rise in silicon, diminish in carbon, was first noticed in some laboratory experiments eighteen years ago by Mr. Edward Riley. This will be again referred to further on. Whilst the scope of the experiments described in the present paper is in no way to deal with material other than malleable compounds of iron and silicon with small quantities of iron and manganese, it may be useful to give some general reference to previous experiments.

The only commercial employment of silicon with other metals is that of silicon bronzes. Silicon is stated to act upon the copper in a manner similar to that of phosphorus. The qualities of such alloys are great strength and tenacity, high electrical conductivity, and resistance to corrosion. Wire made of this material is stated to have a conductivity of 80 per cent., and a tensile strength of about 36 tons per square inch.

Mr. Warren, in a recent number of the *Chemical News*, states that silicon, when in the nascent state, converts platinum into a brittle silicide, or by heating graphitoidal silicon in contact with

platinum to a full red heat, combination at once takes place, resulting in a brittle regulus, containing as high as 10 per cent. of silicon, which is fusible at a red heat, and breaks with a crystalline fracture.

Silver and gold are reported as not presenting any great affinity towards silicon, but on heating a mixture of potassium silico-fluoride with either silver or gold in an amorphous condition to a high temperature, a well-fused regulus of silicide of the metal may be obtained. In the latter instance an alloy containing 5 per cent. of silicon is almost as brittle as antimony. Silver, when alloyed with 10 per cent. of silicon, is stated to have a slightly red tint.

Rich cast iron alloys of silicon are now usually described as ferro-silicon and silicon-spiegel, respectively, the latter containing manganese in addition to silicon. Silicious alloys of cast iron were usually known as glazed pigs, owing to their peculiarly glazed appearance when fractured. It is curious that this very material —burnt pig, as it was often called, and only then made accidentally—was formerly thrown on one side as useless, whereas now it is made purposely on a commercial scale and in large quantities,—another of the many proofs of the advantage of bringing scientific knowledge to bear upon industrial metallurgy. Such ferro-silicon, by itself, is perfectly useless in the refinery or puddling furnace, or for iron castings. The early samples of silicious iron seldom contained more than from 4 per cent. to 6 per cent. of silicon, but Mr. Riley of London, in 1872, was the first to point out that rich ferro-silicon was likely to play an important part in metallurgical industry. By means of laboratory experiments he made in the crucible samples containing as high as 22 per cent. of silicon. He also discovered that, as silicon increased, carbon decreased, until with 20 per cent. of the former the latter is not present in quantities of more than $\frac{3}{4}$ per cent. to 1 per cent., and the greater part of this small amount existed as graphite. Spiegeleisen and ferro-manganese are the richest carbon alloys that can be produced, and they contain about 6 per cent. of carbon; ordinary cast iron rarely exceeds about 4 per cent., and never contains more than about $4\frac{1}{2}$ per cent. So strong, however, is the action of silicon in preventing carbonisation, even in the presence of a large excess of carbonaceous fuel,

that in silicon-spiegel—an alloy of iron, manganese, silicon, and carbon, and notwithstanding the presence of a large amount of manganese—it (that is the silicon) has still the upper hand, and prevents, as in the case of ferro-silicon, carbonisation taking place. A few typical analyses of ferro-silicon, silicon-spiegel, ferro-manganese, and spiegeleisen may be of interest here (see Table I.), but for a fuller description, and of the methods of manufacture employed in their production, reference is given to Mr. Holgate's admirable paper on "The Composition of Ferro-Manganese and Ferro-Silicon made in the Blast Furnace." The writer is indebted to this paper for the analyses in question. Four of the samples quoted represent spiegel and ferro-manganese, and it is interesting to note that, as the manganese rises, there is a gradual increase of carbon up to as high as 7 per cent. A noteworthy fact is, that if silicon, even in 50 per cent. ferro-manganese, is allowed to reach 4 per cent., the carbon is at once much reduced, in some cases to the low amount of about $2\frac{1}{2}$ per cent. This action is still more intensified in the alloys known as silicon-spiegel or silicide of manganese, of which two analyses are given. From the latter it will be seen that, provided the silicon exceeds 10 per cent., the carbon is reduced to an exceedingly low point, and that, although manganese may be present even in comparatively high percentages, this is quite immaterial. This decrease of carbon takes place both in the combined and in the graphitic form, but principally in the former. A very valuable property of these spiegel alloys is the fact that they contain practically no sulphur, the much-dreaded enemy of the steel-maker.

It will, therefore, be seen that in the blast furnace, somewhat strange to say, silicon cannot be reduced unless carbon is also present, and yet, when reduction of silicon occurs with the production of highly silicious iron, carbon is practically absent in the resultant material. The late Dr. Percy, more than twenty years ago, referred to this in his "Metallurgy," and said that, according to his experience, no reduction can take place when silica and iron, without carbon, are heated together, even at the highest furnace temperature. Possibly this might now be accomplished in powerful electric smelting furnaces, and it would be interesting to know whether alloys as rich in silicon as the present valuable alloys of ferro-manganese are rich in manganese

could be produced. If so, without doubt considerable employment could be found for them in metallurgical industry.

TABLE I.

| | Analysis per Cent. | | | | Remarks. |
|---|---|---|---|---|---|
| | Carbon. | | Silicon. | Manganese. | |
| | Graphite. | Combined. | | | |
| Analyses of *spiegel* and *ferro-manganese*, showing the gradual increase of carbon as the manganese increases | ... | 4·27 | ·110 | 8·11 | Sulphur and phosphorus practically absent, remainder being iron. |
| | | 4·78 | ·52 | 19·74 | |
| | | 5·63 | ·42 | 41·82 | |
| | | 6·53 | ·97 | 80·04 | |
| | | 7·20 | ·14 | 80·04 | |
| Analyses of *special manganese*, showing that if the silicon becomes high the carbon diminishes very considerably | ... | 3·56 | 4·90 | 23·90 | Ditto. |
| | | 2·56 | 4·20 | 50·00 | |
| Analyses of *silicon-spiegel* or *silicide of manganese* | ·33 | 1·85 | 10·74 | 19·64 | Ditto. |
| | ·67 | ·98 | 12·60 | 19·74 | |
| | ·90 | ·30 | 15·94 | 24·36 | |
| Analyses of *ferro-silicon* | 2·35 | ·05 | 8·77 | 2·42 | Ditto. |
| | 1·85 | ·06 | 11·20 | 2·78 | |
| | 1·20 | ·23 | 14·00 | 1·95 | |
| | ·55 | ·11 | 17·80 | 1·07 | |

These analyses are from a paper by Mr. Holgate, Assoc. R.S.M., Darwen, on "The Manufacture of Ferro-Manganese and Ferro-Silicon in the Blast Furnace."

Alloys or compounds of iron, carbon, and silicon, non-malleable in their nature, and coming under the term "cast iron," have been thoroughly investigated in this country by Mr. T. Turner of Birmingham, and the results have been placed before this Institute, so that it is unnecessary to do more than touch upon the matter here. Great credit is due to this investigator for the lengthy and valuable researches he has made in the direction indicated, as also to Mr. Keep, of Detroit, U.S.A., who has lately presented interesting papers on the same subject to the American Institute of Mining Engineers. Mr. Keep sums up so well the general results of all investigations up to date, that it may be well to briefly mention them, especially as some of the remarks apply, to some extent, to the malleable compounds or alloys of iron and silicon now being described. Both Mr. Keep and Mr. Turner find that white carbonaceous cast iron, which would invariably

give porous and brittle castings, are made free from honeycombs and possess much greater strength by the addition of comparatively small amounts of silicon. The latter result is one which was considered contrary to previous experience. If further additions are made, say up to 2 per cent., the iron becomes grey, and at this point the maximum strength is obtained. If more silicon is added, although the iron becomes still more grey, it also becomes weaker. By a still further addition, a closer grain results, but the iron is even more brittle than in its white condition. Too much silicon also produces, as in the silicon steel now being described, lack of fluidity and greater shrinkage. Mr. Keep thinks that silicon in cast iron is evidently to some extent combined with the iron and carbon, but whether it exists also in a form corresponding with graphitic carbon mechanically mixed with the remaining mass, is a question still in dispute and unanswered. As is now well known, the principal effect of silicon is to change the carbon from the combined to the graphitic state. One point particularly mentioned by Mr. Keep, and an important one, is that silicon irons have always had the reputation of imparting fluidity to other brands, and naturally this was at first supposed to be owing to the silicon added. It has now been found that this is not directly so, and that it is from the fact that the silicon present causes an increase in the quantity of graphite, and consequently a more fluid cast iron. Silicon is not, therefore, directly the cause, except by its indirect action on the carbon.

In conclusion on this point, as Mr. Snelus said more than seventeen years ago, it is generally supposed that the absorption of much silicon tends to set free the carbon in the graphitic state. No statement more concisely expresses the influence of silicon on what is termed cast iron than that given some eight years ago by Mr. C. F. King, of Newport, U.S.A., in an able paper read before the American Institute of Mining Engineers on "The Chemical Action of the Bessemer Process." He said it is due to the presence of silicon in pig iron that carbon is set free on cooling, and it is in proportion to the elimination of the silicon that the carbon remains chemically combined. Mr. King gives a diagram showing the rate of elimination of the metalloids in the process named, and it is a somewhat remark-

able coincidence that the percentage point (1·8 per cent. Si) where the diminishing silicon curve cuts the combined carbon and graphitic curves, is exactly that which gave the maximum tensile strength in the material made by Mr. T. Turner, and later by Mr. Keep, in their numerous tests as to the effect of silicon upon cast iron. That diagram, reproduced in this *Journal* (Diagram I.), shows that by a diminution in the silicon highly graphitic pig iron becomes rapidly mottled, and eventually white, although practically none, or but little, total carbon is oxidised; and this, as far as can be seen, is solely by the fall of the silicon from 2·50 to 1·70 per cent. Whilst, therefore, Messrs Turner and Keep show that white iron can be converted into mottled, and eventually into grey pig, by means of additions of silicon, this diagram shows the converse, namely, that with silicon abstracted, cast iron becomes mottled, and eventually white.

Outside, one might say even within, the laboratory, the properties of the metalloid silicon or silicium are but little known. No fuller details can be found than in that part of Dr. Percy's "Metallurgy" relating to silicon, where all the methods for its production on a laboratory scale are given.

It is ordinarily described as a non-metal, very hard, dark brown in colour, a non-conductor of electricity, lustrous, not readily oxidised, and soluble in all ordinary acids, with the exception of hydro-fluoric. It is said to resemble carbon in its general properties; others add that it exists like carbon in a graphitic, amorphous, and combined or adamantine form, but this has still to be determined.

Mr. Henry J. Williams, St. Louis, Missouri, U.S.A., this year presented a paper to the American Institute of Mining Engineers on "The Determination of Silicon in Ferro-Silicons, its Occurrence in Aluminium as Graphitoidal Silicon, and a Study of its Reactions with Alkaline Carbonates." As the latest investigation of this kind, it may be well to refer to the experiments. Mr. Williams' method of determining the metalloid was by means of fusion with sodium carbonate, the idea being to dissolve it as soluble sodium silicate, and leave the iron in a very spongy and finely divided condition, so as to be readily attacked by acids. He noticed some curious facts during fusion. As soon as the sodium carbonate was thoroughly melted and the heat reached its maximum,

the reaction became very violent, bubbles of gas (carbonic acid) rising to the surface and bursting into flame. This had been noticed before by another observer, making experiments of similar nature with graphitic pig iron. Mr. Williams was, however, somewhat puzzled, the ferro-silicon with which he was experimenting being high in silicon and comparatively very low in carbon, and yet it gave the same result. To ascertain why silicon acts exactly like carbon during the reduction, he endeavoured to obtain an iron entirely free from foreign elements—particularly carbon—while containing high silicon, but he was unsuccessful. He found the desired condition realised in the aluminium of commerce, most of which, in spite of its name, he states contains not less than 3 per cent. or 4 per cent. of silicon, but, of course, no carbon. He found that a large part of the silicon in such aluminium seemed invariably present as an allotropic modification of that metalloid, crystallising in fine glistening black plates, resembling some forms of graphite, and he considered that this was evidently the graphitoidal form of silicon which Deville has mentioned in connection with aluminium, but which has not yet been isolated or found to exist in iron. Dr. Percy mentioned at length the same fact, and describes the material as resembling graphite from iron-smelting furnaces, and as being hard enough to scratch glass, with a specific gravity of 2·49. As regards, however, the form that silicon may take in cast iron or steel, Mr. Keep considers that, whether it exists in a state corresponding to graphitic carbon, and mechanically mixed with the remaining mass, is still a question in dispute. Mr. Holgate of Darwen, also, in the paper before referred to, after making many analyses, says he has never found any evidence as to the existence of graphitic silicon in such alloys, though he has noticed some slight difference in the behaviour of silicon when dissolved in acids. Mr. Turner, in his paper some two years ago, after carefully investigating this point, both by means of experiments of his own, and of those of Sir Frederick Abel, Mr. Snelus, and others, says that it may be considered that in a vast majority of cases, at least, silicon has only one form. Finally, therefore, the practical metallurgist has at present apparently no means of readily determining this point, although he may have reason to think that silicon does vary its form in cast iron or steel.

In metallurgical literature, but little reliable information is to be found as to the effect of silicon upon iron. Mr. Howe in his excellent work on "The Metallurgy of Steel" gives an excellent *résumé* of what has appeared. Some fourteen years ago, in America, good results were promised by a process which was to use "Codorus, or silicon ore," as it was termed. This was to dephosphorise or neutralise the phosphorus in the metal under treatment. Only a few years back, the writer had reason to investigate this matter in America, but found that this so-called puddled silicon iron or silicon steel contained no silicon. The whole matter was happily summarised by the well-known metallurgist, A. L. Holley of America, who said, or rather sang, of it:—

"There was an old man of Codorus,
Who said he took out the phosphorus,
So the iron he puddled, and with chemicals muddled,
But the puddling took out the phosphorus."

Referring now to the consideration of silicon alloyed with the metal iron, the common belief has been that steel which has to be used in its forged state should contain practically none, or as small an amount as possible. Any quantity exceeding ·10 per cent., or up to ·20 per cent. at most, has been considered to be highly injurious. "Give a dog a bad name" is well illustrated in the present case, as will be seen from the results and tests given. At any rate, it may be safely said that silicon has been blamed in a somewhat hasty manner. This blame may be well deserved in alloys of carbon, silicon, and iron, as such alloys, as regards ductility, have no doubt proved unreliable and of little value, but the blame has been put at the door of silicon, whereas it is now proved that silicon, alloyed with iron, provided carbon is absent, or only present in small amounts, gives good tests as to toughness and malleability. It will be seen that 1½ or even 2 per cent. may be present, and yet the material may possess 25 to 30 per cent. elongation; whereas the same percentage of carbon, alloyed with iron, would give a product barely malleable and one possessing but little elongation under tensile stress. Whilst, therefore, the common belief that alloys of carbon, silicon, and iron are brittle, or even dangerous, is quite correct, the cause is not due to silicon only, but to the combination of

silicon with carbon and iron, a case parallel to some extent to that pointed out by the well-known Terre-Noire Company's experiments, where it was proved that phosphorus may be present in iron, provided the carbon is low and the manganese high, a fact (that is, as regards phosphorus) still more prominent in wrought irons. As also pointed out by Mr. Howe, "silica is often mistaken for silicon; who knows how far it is responsible for this metalloid's bad name?" This was actually noticed by Mr. Turner in test bars of steel, containing comparatively low percentages of silicon, that is, under ·5 per cent., much of the silicon present being in the oxidised condition.

According to M. Gautier, also, there is a difference between steel made with silicon only and that with silicon and manganese, *i.e.*, between a product made by adding ferro-silicon (carbon, silicon, and iron alloy), and that with silicon spiegel (carbon, silicon, manganese, and iron alloy), and he mentions the following interesting experiment by his then colleague, M. Pourcel.

In a porcelain tube were placed two receptacles, one holding steel made by adding ferro-silicon only, and the other steel by an alloy of silicon spiegel. A current of chlorine was passed until all the iron was removed in the state of chloride. It was then seen that in the first receptacle there remained a network of silicate of iron, preserving the original formation of the piece, whilst steel by silicon and manganese alloy left no residuum. Also, that such steel with no manganese was red-short, lacked fluidity, and possessed other defects. The writer has, however, not noticed such difference in the material now described, which, in its molten state, pours well, the ingots forging easily, and up to 2 per cent. silicon the ductility in the testing machine being very good.

However, as suggested by Mr. Howe, possibly silicon may enter into different combinations in steel, some promoting, some impairing ductility and malleability. In favour of this is the fact that so many well-known scientists and metallurgists have utterly condemned in forged steel the employment of silicon, even if present in small amounts. Such strong opinions would not be expressed without good grounds, and a reasonable explanation for the apparent discrepancy noticed by different observers seems to some extent to be in the direction named. At any rate,

the samples described in this paper, and containing up to 2 per cent., present a remarkable ductility and toughness, both in the bending and in the tensile specimens.

The writer wishes it to be understood that he does not claim that silicon should take the place of carbon. Smaller quantities of carbon produce the requisite hardness and different tempers required in the industrial application of steel, and, in fact, silicon alone does not produce a steel that will harden by water-quenching, thus in this respect resembling manganese steel. Still it is a somewhat remarkable fact that a steel (specimen C., Table II.) containing 1·60 per cent. of silicon, a metalloid ordinarily so much distrusted, stretched 35·10 per cent. (on 2″) with 54·52 per cent. reduction in area, and a test bar from the same material, tested by Professor Kennedy, gave 24·30 per cent. (on 10″) with 58·30 per cent. reduction in area. Had not the specimen D., tested by Professor Kennedy, broken in the threads (the diameter of the bar over the threads being only ·93″ against ·898″ of the tested part of the bar, too small a difference in the holding part), no doubt his test would have confirmed the writer's, that a material with even 2·13 per cent. of silicon can elongate 36·50 per cent. on 2″ (equivalent to about 27 per cent. on 10″) with 59·96 per cent. reduction in area. So that, whilst it may not be advisable to use silicon as a hardener in making steel, it is important to have proved that the brittleness noticed in ordinary so-called silicon steel is due rather to the combined presence of the two hardeners, silicon and carbon. It may be here mentioned that the ductility noticed cannot be attributed to manganese, which was only present in small quantities, about ·20 per cent. to ·30 per cent.

The material employed in these experiments was made by melting in crucibles good wrought iron scrap, low in sulphur and phosphorus, to which was added, in varying and increasing quantities, rich ferro-silicon containing 20 per cent. of silicon. The ingots, $2\frac{1}{2}''$ square, were reduced by forging in the ordinary method to $1\frac{3}{4}''$ square billets, then rolled down to bars $1\frac{1}{8}''$ diameter.

The effect of silicon upon iron is as follows:—1. In its forged condition. 2. In its cast condition.

1. Forged condition. The forge reports that the material A.

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(Table II.) (·24 per cent. Si) did not forge well, cracking somewhat whilst being hammered, but all the other samples, B. to H. (·79 per cent. to 5·53 per cent. Si), when forged at a fair yellow heat, required no special care, thus clearly showing that silicon, even up to as high as about 6 per cent., does not destroy the malleability of the metal iron. Upon, however, exceeding this percentage the material is red-short, crumbles at a low heat, and notwithstanding the low percentage of carbon present (·25 per cent.) becomes really a species of cast iron. It should also be here mentioned that, if the carbon had been higher, the point at which malleability ceases would have been with a much lower percentage of silicon. Nor is such red-shortness removed by the addition of manganese.

It may also be here mentioned, that no return of strength takes place by a further addition of silicon, as is so specially characteristic of manganese steel. Any further addition merely increases its resemblance to silicious cast iron. Nor do gradually increasing percentages, as is the case with manganese steel, destroy the magnetic properties of the alloy, a 7 per cent. material seeming to be quite as susceptible as ordinary iron or steel drillings.

As regards the results of the mechanical tests on this steel in its forged state, these are so fully detailed in Table II. (Tensile and Bending Tests), Table III. (Compression Tests), and Diagram III. that it is only necessary to add a few remarks here.

Apparently silicon, up to $1\frac{1}{2}$ or $1\frac{3}{4}$ per cent., added to iron, although increasing the limit of elasticity, and raising the tensile strength, does not impair ductility; but after this the further increase of tensile strength noticed is only obtained with a serious loss of ductility. Apparently there is no sharp line of demarcation, but after exceeding about $1\frac{1}{2}$ to 2 per cent., further slight increases cause great changes in the characteristics of the material. In this respect, therefore, its action rather resembles that of carbon, in contradistinction to the action of manganese, of which larger amounts are required to effect similar changes.

The fractures from the tensile test bars, up to "D" specimen, (2·18 per cent. Si) are silky, after this completely and coarsely crystalline. As in the specimens in the cast state, neither annealing nor water-quenching seem to have any effect on the structure.

The annealed flat bending pieces, half-an-inch wide by one-fourth of an inch thick, gave good results, specimens A., B., C., and D. (·24 per cent. to 2·18 per cent. Si) bending double cold without fracture, more like soft steel, and after being bent double the pieces were flattened close together cold, without showing signs of fracture. Specimen E. (2·67 per cent. Si) also bent double cold, but broke in the radius with the last blow. F. (3·46 per cent. Si) was much stiffer, bending only to a right angle. G. and H. (4·49 per cent. and 5·53 per cent.) would not bend at all, and were exceedingly brittle. These bending tests were confirmed by Mr. Turner's experiments with bars of the same size. Up to D specimen the samples bent to an angle of 180°, with one-eighth of an inch radius.

Pieces from the bars used for bending tests were also tested for weldability, but entirely without success. The writer's experience has always been that silicon is quite fatal to welding, notwithstanding that the contrary might be expected from the fact that silica is of such material assistance in welding wrought iron.

As regards water-quenching or hardening, samples A., B., C., and D. (·24 per cent. to 2·18 per cent. Si) were unaffected, *i.e.* unhardened, by even the highest heat. Even if plunged at welding heat into water made specially cold, no hardening beyond a surface stiffening took place, nor did their toughness seem impaired by this treatment. Specimen E. (2·67 per cent. Si) was heated to an ordinary yellow heat, and plunged into cold water at about 70° Fahr. This piece was much stiffened, but only broke on being bent double. Another piece of the same material, heated to a welding heat, and plunged into water at about 52°, also proved very stiff, and only broke when bent double. Sample F. (3·46 per cent. Si) was only stiffened by being water-quenched at a welding heat. It was just as brittle as before, and had not hardened, being easily touched by a file. In this respect, therefore, *i.e.*, as to being toughened by water-quenching, this material differs from manganese steel. The heating did not cause much alteration in fracture, the crystallisation being still open and coarse. H. (5·53 per cent.) was quenched both at ordinary heat and at a welding heat, and although the surface was skin-hardened, upon being fractured it was easily filed.

These tests, therefore, clearly prove that silicon does not confer the same property as carbon does upon iron, *i.e.*, of becoming hardened when dipped hot into a cooling medium. It should also be stated that the whole of the samples were subjected to high heats, even to a welding temperature, without falling to pieces. In fact, as regards this point, they behaved more like mild steel, apparently proving that silicon itself does not cause iron to become red-short.

That silicon steel has a certain kind or degree of softness or lack of body compared with carbon steel is especially brought out in the compression tests (Table III.), where sample E., although apparently very hard and brittle (high in the scale of Turner's hardness tests, viz., 33), crushed up 38 per cent. of its length under a compression load of 100 tons per square inch. A correspondingly hard temper of carbon or tungsten steel would not shorten more than 20 per cent, or, if hardened, would remain unaltered. A very mild steel, containing not more than ·20 per cent. of carbon, would not shorten much more than this sample containing over $2\frac{1}{2}$ per cent. of silicon. At any rate, therefore, silicon is not so powerful a hardener of iron as is carbon. Mr. T. Turner has tested this material in his sclerometer, or hardness testing machine, the results of which are given under this head in Table I.

TABLE III.

*Compression Tests.*

| Series. | Test Bar Mark. | Analysis per Cent. | | | Load applied in Tons per Square Inch. | Reduction in Length produced by Load. | Diameter Increased to |
|---|---|---|---|---|---|---|---|
| | | Carbon. | Silicon. | Manganese. | | | |
| B | 205 | ·18 | ·79 | ·21 | | Before being Tested. 1·0 | ·7977 |
| No. 205 gave a sharp indication at 32 tons. | | | | | 10 | ·9958 | ·799 |
| | | | | | 20 | ·9915 | ·800 |
| | | | | | 30 | ·9472 | ·822 |
| | | | | | 40 | ·853 | ·8895 |
| | | | | | 50 | ·814 | ·894 |
| | | | | | 60 | ·7305 | ·95 |
| | | | | | 70 | ·658 | 1·002 |
| | | | | | 80 | ·5975 | 1·056 |
| | | | | | 90 | ·547 | 1·115 |
| | | | | | 100 | ·503 | 1·153 |

TABLE III.—*continued.*

*Compression Tests.*

| Series. | Test Bar Mark. | Analysis per Cent. Carbon. | Silicon. | Manganese. | Load applied in Tons per Square Inch. | Reduction in Length produced by Load. | Diameter Increased to |
|---|---|---|---|---|---|---|---|
| E | 206 | ·20 | 2·67 | ·25 | | Before being Tested. 1·009. | ·7979. |
| No. 206 gave no indication of set by pointer. | | | | | 10 | 1·009 | ·7979 |
| | | | | | 20 | 1·008 | ·8000 |
| | | | | | 30 | ·9915 | ·808 |
| | | | | | 50 | ·901 | ·850 |
| | | | | | 100 | ·622 | 1·0345 |

| Series. | Test Bar Mark. | Analysis per Cent. Carbon. | Silicon. | Manganese. | Load applied in Tons per Square Inch. | Reduction in Length produced by Load. | Diameter Increased to |
|---|---|---|---|---|---|---|---|
| F | 207 | ·21 | 3·46 | ·29 | | Before being Tested. 1·009. | ·7985. |
| No. 207. No indication of set by pointer. | | | | | 10 | 1·009 | ·7985 |
| | | | | | 20 | 1·009 | ·795 |
| | | | | | 30 | 1·0045 | ·8000 |
| | | | | | 100 | ·6455 | 1·0115 |

| Series. | Test Bar Mark. | Analysis per Cent. Carbon. | Silicon. | Manganese. | Load applied in Tons per Square Inch. | Reduction in Length produced by Load. | Diameter Increased to |
|---|---|---|---|---|---|---|---|
| G | 208 | ·25 | 4·49 | ·36 | | Before being Tested. 1·008. | ·7985. |
| No. 208. No indication of set by pointer. Gave several loud reports as pressure was increased up to 50 tons, and then ceased. | | | | | 10 | 1·008 | ·7985 |
| | | | | | 20 | 1·008 | ·7985 |
| | | | | | 30 | 1·0045 | ·8000 |
| | | | | | 40 | ·9895 | ·806 |
| | | | | | 100 | ·683 | 1·003 |

In order to test this steel in the shape of wire, samples E. (2·67 per cent. Si) and G. (4·49 per cent. Si) were reduced to rods, and Messrs. Shipman & Co., of Sheffield, kindly undertook

to draw them into wire. The G. material, though readily rolled into rods, would not, however, draw, nor did annealing soften or give it the requisite ductility. In the rod state the tensile strength was 59 tons per square inch, with 12 torsions in 8 inches. Crucible carbon steel would stand about the same test, and Swedish Bessemer, with high carbon, is slightly higher in torsion, but lower in tensile strength.

The material E. was readily drawn to No. 20 B.W.G., standing 180 lbs. tensile strength (64 tons per square inch), with 157 torsions in 8 inches. Annealing lowered the tensile strength to 120 lbs. (about 48 tons per square inch), and slightly increased the torsions to 169 in 8 inches. The wire-makers endeavoured to harden both G. rods and E. wire, first in oil, and then in water, but without success.

Professor Barrett, F.R.S., of Dublin, has kindly undertaken to determine the electrical properties of the steel wire just mentioned, but the results are not yet completed. About twelve months ago, the writer, thinking that silicon might confer upon iron qualities suitable for the manufacture of magnets, sent to Mr. Bottomley, in Sir W. Thomson's laboratory at Glasgow, a forged sample containing 4·43 per cent. of silicon, and ·18 per cent. of carbon.

The results of Mr. Bottomley's experiments, as will be seen from diagram No. III., were unfavourable. He found that the material had less susceptibility and more retentiveness than good soft iron, and that it had enormously less retentiveness than hard steel suitable for magnet-making. The diagram shows two curves "A" and "B," "A" showing the retentiveness of the bar and "B" the susceptibility. The dotted curve "C" represents what the bar should be if it were suitable for magnet-making, and the dotted curve "D" what it would be were it good soft iron.

Considerable attention having been given to the curious non-magnetic properties of manganese steel, the writer was led to make the approximate tests detailed in Table IV., to see if iron, alloyed with other elements than manganese, would also lose its magnetic susceptibility. From the list given, it will be seen that practically manganese is the only exception, for as regards ferro-chrome, it is only when very high percentages of chromium, and but comparatively small amounts of iron are present, that the material is not susceptible.

TABLE IV.—*Non-Malleable Ferro-Alloys.*

| Name of Alloy. | Special Constituents. | Composition per Cent. (in some cases approximate). | | | | | | | | | Magnetic Susceptibility. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | C. per Cent. | Si. per Cent. | S. per Cent. | P. per Cent. | Mn. per Cent. | Cr. per Cent. | W. per Cent. | Al. per Cent. | Fe. per Cent. | In Bulk. | In Drillings or Powdered State. |
| Spiegeleisen . . | Manganese | $4\frac{3}{4}$ | ... | ... | ... | 14 | ... | ... | ... | $81\frac{1}{4}$ | Attracted. | |
| Spiegeleisen . . | Manganese | $5\frac{1}{2}$ | ... | ... | ... | 36 | ... | ... | ... | $58\frac{1}{2}$ | Not attracted. | Very slightly influenced. |
| Ferro-manganese . | Manganese | 7 | ... | ... | ... | 82 | ... | ... | ... | 11 | Not attracted. | Very slightly influenced. |
| Ferro-silicon . . | Silicon . . | 1 | 16 | ... | ... | 1 | ... | | ... | 82 | Strongly attracted | |
| Ferro-silicon . . | Silicon . . | $\frac{3}{4}$ | 20 | ... | ... | 2 | ... | ... | ... | $77\frac{1}{4}$ | Strongly attracted. | |
| Silicon-spiegel . . | Manganese and silicon | 2 | 8 | ... | .. | 20 | ... | ... | ... | 70 | Easily attracted. | |
| Silicon-spiegel . . | Manganese and silicon | $1\frac{1}{2}$ | 16 | ... | ... | 20 | ... | ... | ... | $62\frac{1}{2}$ | Strongly attracted. | |
| Ferro-chrome . . | Chromium | 4 | 1 | ... | ... | 1 | 8 | ... | ... | 86 | Strongly attracted. | |
| Ferro-chrome . . | Chromium | 5 | 2 | ... | ... | 1 | 28 | ... | ... | 64 | Strongly attracted. | |
| Ferro-chrome . . | Chromium | 5 | 1 | ... | ... | 1 | 63 | ... | ... | 30 | Not attracted. | Very slightly influenced. |
| Ferro-chrome . . | Chromium | 5 | 2 | ... | ... | 1 | 79 | ... | ... | 13 | Not attracted. | |
| Ferro-aluminium . | Aluminium | 1 | $1\frac{1}{2}$ | ... | ... | ... | ... | ... | 10 | $87\frac{1}{2}$ | Strongly attracted. | |
| Ferro-aluminium . | Aluminium | 3 | $1\frac{1}{4}$ | ... | ... | ... | ... | ... | 12 | $83\frac{1}{2}$ | Very strongly attracted. | |
| Ferro-aluminium . | Aluminium | 3 | $1\frac{1}{2}$ | ... | ... | ... | ... | ... | 18 | $77\frac{1}{2}$ | Very strongly attracted. | |
| Ferro-aluminium . | Aluminium | 1 | $1\frac{1}{2}$ | ... | ... | ... | ... | ... | 20 | $77\frac{1}{2}$ | Slightly attracted. | Strongly attracted. |
| Ferro-tungsten | Tungsten . | 4 | 1 | ... | ... | 1 | ... | 40 | ... | 54 | Very strongly attracted. | |
| Ferro-phosphorus. | Phosphorus | 1 | $\frac{1}{2}$ | ... | 10 | 4 | ... | ... | .. | $84\frac{1}{2}$ | Strongly attracted. | |
| Ferro-sulphur . . | Sulphur . | $\frac{1}{2}$ | $\frac{3}{4}$ | 5 | ... | ... | ... | ... | ... | $93\frac{3}{4}$ | Strongly attracted. | Strongly attracted. |

## *Malleable Ferro-Alloys.*

**Malleable compounds of iron with other elements so far experimented upon (including carbon, silicon, sulphur, phosphorus, chromium, tungsten, aluminium, and nickel) are strongly susceptible to magnetization.**

**Alloys of manganese and iron, however, form an exception to this. As is now well known, in manganese steel, as soon as the manganese exceeds 8 or 9 per cent., the material is only attracted when in a finely divided state such as drillings or powder, and with further increase of manganese even this slight susceptibility disappears. The same fact is noticed as regards the non-malleable compounds of iron and manganese. Alloys of iron, nickel, and manganese are also not susceptible.**

2. Cast state. As might be expected, the whole of the samples are very free from honeycombs, but this soundness in the cast is only acquired at the expense of toughness or ductility. As regards this freedom from honeycombs, it may be of interest to state here that although silicon does produce soundness in steel, yet Mr. Holgate noticed that in making ferro-silicon of 13 to 15 per cent., there is in casting an unusually large outburst of gas, and the pigs are exceedingly full of honeycombs. A sample is exhibited among the specimens accompanying this paper. In watching a cast of material of this percentage from the blast furnace, he noticed that when the exterior of the pigs became almost solid, and whilst the interior was still liquid, the metal began to boil up, and frequently for fifteen or twenty minutes some cwts. of metal in each bed boiled over, this going on until the pigs were quite set and solid.

It would be interesting to know what is the cause of this outburst, and the composition of the escaping gases. It has been stated in metallurgical literature that in some hot overblown Bessemer charges silicon may be present in considerable percentages, and yet the steel may rise or boil over when poured into ingot moulds.

Silicon steel pipes, or settles, to a much greater extent than ordinary steel, and this in itself is a considerable disadvantage. Its fluidity when being poured is less than that of ordinary steel. The crystallisation or form of fracture of the lower percentages is somewhat like ordinary mild cast steel, but on exceeding about $2\frac{1}{2}$ per cent. silicon a striking change occurs; the crystals become very larged, glazed in appearance, and cleave somewhat after the nature of spiegeleisen. As this large and marked crystallisation increases, the material becomes exceedingly brittle, and if still further additions are made, the appearance of the material approaches silicon pig iron, and is non-malleable.

High percentages of silicon in the cast or unforged material cause a considerable increase in shrinkage or contraction. This point is already a difficult one with the steel-founder, who for many years has been on the horns of the dilemma, that whilst silicon increases soundness, it increases the tendency of castings to draw. This fact of silicon also increasing contraction in cast iron has been noticed by Mr. Keep.

As in the forged, so also in the cast material, when the silicon exceeds about 2 per cent., and the peculiar crystallisation noticed in the samples exhibited commences, neither annealing nor water-quenching seems to have any effect in changing the structure.

It is well known that considerable difficulty is experienced in dissolving drillings of ferro-silicon ; so tedious is the process, that recourse is usually had to the sodium carbonate process. This is not requisite with silicon steel, which requires only the ordinary hydrochloric acid method. The silica residue is very clean and free from iron.

A considerable number of estimations have proved that the silicon is very uniform and homogeneous in this steel. Analyses taken from different parts of the same ingot and bar give results very similar to each other. No traces of graphite are noticed, the carbon being always present in the combined form. If the material analysed is in the form of drillings, they keep their shape, the iron being dissolved out.

Experiments have been made with this steel in comparison with other material as regards its corrosion. Table V. gives the time of immersion in the sulphuric acid, and the loss.

In conclusion, the author wishes it to be understood that he does not claim that there is any field for the employment of such an alloy, or high silicon steel, as that here described. This paper is presented only for the purpose of scientific interest, and in order to place on record the actual effect of the metalloid silicon on iron. Silicon cannot take the place of carbon ; the latter has always the advantage of being more easily applied, and of producing a material more suited to the various requirements of users of steel.

It is also clearly proved by these experiments that silicon, unlike carbon, does not confer upon iron the property of becoming hardened when water-quenched.

TABLE V.—*Corrosion Experiments.*

| | | Percentage of Silicon. | Strength of Acid ($H_2So_4$). | Length of Immersion. | Loss per Cent. | Colour after Treatment. | Remarks. |
|---|---|---|---|---|---|---|---|
| Silicon steel (C.) . . | Bar | 1·60 | 50 per cent. | 21 days | 6·32 | Very bright. | After being taken out of the acid and dried, the silicon steel and wrought iron appeared as if burnished, and retained their brilliancy for some time. |
| ,, ,, (E.) . . | ,, | 2·67 | ,, | ,, | 3·32 | Very bright. | |
| ,, ,, (G.) . . | ,, | 4·49 | ,, | ,, | 4·29 | Very bright. Soon dulled over, although carefully covered up. | |
| Ordinary mild steel . | ,, | ... | ,, | ,, | 7·48 | Dull bright. | |
| Wrought iron . . . | ,, | ... | ,, | ,, | 4·47 | Most brilliant. | |
| Silicon steel (E.) . . | Wire 20 B.W.G | 2·67 | ,, | ,, | 31·80 | Very bright. | |
| Ordinary mild steel . | ,, | ... | ,, | ,, | 17·29 | Dull. | |
| Ordinary wrought iron | ,, | ... | ,, | ,, | 17·09 | Very bright, like wrought bar. | |
| Manganese steel . . | ,, | Mn (12 %) | ,, | ,, | 51·18 | ... ... | |

*Moisture Test.*

| | | Percentage of Silicon. | Weight before Placing in Moist Atmosphere. | Weight after Keeping 21 days in Moist Atmosphere. | Increase in Weight. |
|---|---|---|---|---|---|
| Silicon steel (C.) . . | Bar | 1·60 | 20 634 grams. | 20·644 grams. | 10· grams. |

The following Table gives the specific gravities of the silicon steel, as well as that of ferro-silicon:—

TABLE VI.

| | | Percentage of Silicon. | Specific Gravity. | Remarks. |
|---|---|---|---|---|
| Silicon steel (E.) . . | Ingot | 2·67 | 7·38 | |
| " " " . . | Wire 20 B.W.G. | 2·67 | 7·88 | |
| " " (G.) . . | Ingot | 4·49 | 7·54 | |
| Ferro-silicon . . . | ... | 5·00 | 7·00 | |
| " . . . | ... | 8·00 | 6·943 | |
| " . . . . | ... | 16·00 | 5·303 | Doubtful. |
| Ordinary grey cast iron | ... | ... | 7·10 | |

TABLE VII.—*Samples of the Alloys of Iron and Silicon Exhibited in order to Illustrate this Paper.*

SECTION I.—Samples of silicon steel in the cast state, containing from ·24 per cent. to 8·83 per cent. of silicon.

SECTION II.—Samples of silicon steel in the forged state, containing from ·24 per cent. to 5·53 per cent. of silicon.

SECTION III.—Test bars as mentioned in Table II.

SECTION IV.—Bending pieces given in Table II.

SECTION V.—Compression pieces given in Table III.

SECTION VI.—Samples of ferro-alloys to illustrate magnetic properties.

SECTION VII.—Silicon steel wire 2·67 per cent. Si, 20 B.W.G.

Sample of ferro-silicon containing 16 per cent. silicon, yet honeycombed.

Silica from silicon steel.

Other samples.

## *DISCUSSION.*

Mr. F. GAUTIER said that, as Mr. Hadfield had explained in his very valuable paper, few things were known of silicon, and an extensive book might be written on the subject. He did not wish to lengthen the discussion upon it, but he desired to draw attention to a few points. Mr. Hadfield had referred to silicon bronze, and had stated that the only commercial employment of silicon with other metals was for silicon bronze. This kind of bronze was first made in France, and called *bronze silicieux,* for purposes of wires of high electrical conductivity, but there was no silicon at all in it. It was made, he did not know exactly how, although by some process in which silicon was added; but it was to get rid of the oxidation, which was that of copper; and when that oxidation was out, they could find no silicon at all in that kind of bronze. Mr. Hadfield had spoken also of silicon and carbon which could be displaced in the pig iron. It was long since Mr. Snelus had drawn the attention of chemists to that question, but now, after what had been said by Mr. Turner and Mr. Wood, and according to the practical use of silicon in foundries in England and France, it appeared that some light was thrown on the matter. The silicon could go into solution with iron in all proportions, whereas carbon could not go beyond 4 or 5 per cent., when there was no special impurity or other metalloid present. Of course, if there was one body which could be in solution in all proportions, and another in a reduced one, it was easy to understand how a displacement of the carbon by the silicon was possible. It might be remembered that, in a paper which he read on the subject, he showed that the carbon was turned from the combined state into the graphitic one by the silicon. It was a kind of precipitation, just as in the case of camphor dissolved in alcohol, when water was added without limit. With regard to the action of carbonate of soda on ferro-silicon, Mr. Hadfield had spoken of its employment by Mr. Williams, of St. Louis, U.S.A., for the analysis of those alloys, but he had himself stated ten years ago that it was so difficult to make the analyses of the alloys of silicon and iron by the

use of acids, that it was a better plan to arrive at fusion with carbonate of soda; so that it was not quite a new thing. With regard to the graphitic state of silicon in pig iron, Mr. Snelus (whom he did not see present) had published a very interesting paper in the *Proceedings* of the Institute to show that practically it never was possible to find any graphite in silicon, whereas it was easy to find carbon. Some graphitic silicon could be found in aluminium. It was a true chemical process to make graphitic silicon, but the silicon in aluminium had been found some twenty or thirty years ago. Silicon had long been thought to be a very bad thing for wrought iron; and it was not Mr. Howe who discovered that it was not silicon, but silica, which imparted to wrought iron those bad properties. He (Mr. Gautier) had himself been the first to discover that Karsten, the great German chemist, had made the mistake of attributing to silicon what ought to be attributed to silica, in the bad properties of wrought iron. The simple reason was as follows. When wrought iron was produced, oxidising actions were employed, according to which no metallic silicon could remain. It was not at all the same when they were making, for instance, steel by the addition of an alloy containing silicon. Mr. Hadfield had not referred to the experiments of Wenzel Mrázek, the eminent Austrian chemist, who was the first to attract the attention of metallurgists to the effects of low carbon and high silicon in steel. He (Mr. Gautier) had given some details on that subject in the paper which he had written for the Institute on the uses of ferro-manganese.* It appeared to be a general law of nature that carbon, and several other metalloids, could not live on good terms with iron; whereas, when carbon was low, they might have some of those impurities, but not if there was a large proportion of carbon. Mr. Hadfield perfectly well understood the incompatibility of carbon with silicon. Mr. Hadfield did not speak of his own experience on silicon steels. He (Mr. Gautier) had had occasion, at the Hecla Works, to see very splendid tools made with silicon and carbon, where there was $1\frac{1}{2}$ per cent. of silicon, and less than $\frac{1}{2}$ per cent. of carbon. That was a most remarkable feature of silicon steel, and

* *Journal*, No. I., 1876, p. 43.

he was sorry that some specimens of this steel had not been laid on the table.

Mr. Hadfield said that the samples exhibited contained practically no carbon, and were made specially so, in order to see the effect that silicon produced upon iron without other elements being present, or when present only in a small quantity.

Mr. Gautier said that, according to what he had seen, that kind of silicon steel could be hardened very well, but there was some difficulty in heating it. It wanted some care.

Mr. Edward Riley said that he had a tool containing $2\frac{1}{4}$ per cent. of silicon, which turned up at John Fowler's works a cast steel wheel, and it took the skin off with hardening. He had no doubt that silicon, with a little carbon, made a very good tool.

Mr. Hadfield said that there was little to say on the points referred to in the discussion, as they were fully dealt with in the paper itself. In mentioning Mr. Williams' paper, it was not claimed that there was anything new in the method of determining the silicon, but it was interesting, as dealing with the question as to whether silicon had any other form besides the one ordinarily known. With reference to the properties of alloys of carbon, silicon, and iron, these were purposely not dealt with in this paper, as the experiments described were only made in order to determine the effect of silicon upon iron, the carbon being kept as low as possible.

The President said he thought that the convenience of the members would best be consulted by reading the next two papers without any discussion, and then adjourn the discussion to the next meeting in London. They were anxious to hear Mr. Head's paper on a new form of Siemens furnace, and also the paper by Mr. Garrison on the Robert-Bessemer process. He begged to propose the best thanks of the members be given to Mr. Hadfield for his very excellent paper.

The motion was adopted by acclamation.

## CORRESPONDENCE.

Mr. ALEX. POURCEL remarks that they should be grateful to Mr. Hadfield for following up with so much perseverance his very interesting studies, which had already led him to such remarkable discoveries relative to manganese steel.

The few facts which Mr. Pourcel had to mention in support of Mr. Hadfield's statements referring to his experiments on the alloys of iron and silicon were abstracted from a paper which he communicated eleven years ago, on the 7th of September 1878, to *L'Industrie Minérale.*

He then attempted to free silicon from its bad repute, based upon no well-established grounds, of having the most pernicious influence on forged steels, as well as on their mechanical qualities.

In the works of Montluçon-St.-Jacques, under Mr. Mussy's management, before the year 1875, steel had been prepared with 2½ per cent of silicon, and a small percentage of carbon; it had been hammered, and was used for sheet iron and wire without any difficulty. Mr. Hadfield had confirmed this fact by numerous experiments fifteen years later.

The property of silicon of transforming combined carbon into the graphitic state was studied by Captain Caron, Director of the Artillery Laboratory of Saint-Thomas d'Aquin, in 1862, at least twenty-seven years ago. Captain Caron made a report as to the result of his researches to the Academy of Sciences. He was of opinion that the use of silicon should be prohibited in the manufacture of tool-steels, not because that alloy rendered the latter more brittle, but because, in course of time, and under the influence of repeated reheatings, it diminished their hardening properties. A cutting tool was blunted by use, and was restored to its original condition by repeated forging, before it was thrown away; and silicon had the property of displacing at a red heat the hardening carbon; therefore, the hardening property of a steel containing a certain percentage of silicon would be affected by several reheatings.

This criticism did not apply to steels destined for large forg-

ings or for building purposes; and he asserted in 1878 that the comparative experiments made at Terre-Noire on steels containing from ·1 to ·4 per cent. of silicon were nearly identical, the carbon and manganese remaining constant. The property of extensibility was not sensibly altered, whilst the resistance was increased with ·4 per cent. of silicon, instead of ·1 per cent.

From the time that Mr. Pourcel succeeded in the manufacture of silicon-spiegel, in September 1875, at Terre-Noire, he discovered the curious property possessed by silicon of transforming the combined carbon in spiegel into graphitic carbon. He obtained about fifty tons with 6 per cent. of silicon, 7 to 8 per cent. of manganese, and 2½ per cent. of carbon, which, cast in *coquille* (chilled moulds), gave a fracture presenting a fine and grey grain, instead of large white plates. This demonstrated clearly the correctness of Captain Caron's theories.

Mr. Pourcel made the inverse experiment described in his paper, read in 1878 before the *Société de l'Industrie Minérale*, a translation of which appeared in October in *Iron*. He prepared a casting with 3 per cent. of silicon, 2 per cent. of carbon, and ·1 to ·2 per cent. of manganese, which, cooled in chilled cast-iron moulds, presented a grey fracture. About 4 per cent. of manganese having been introduced into this casting, by means of a ferro-manganese containing 85 per cent. of manganese, the grain of the casting became distinct, the carbon having been converted into the combined state. He inferred that for steel castings requiring a strong hardening—projectiles, for instance—it was necessary to introduce a percentage of manganese capable of neutralising the effect of silicon—say, three or four times more manganese than silicon.

The series of castings exhibited in 1878 in Paris by the Terre-Noire Company established the fact that the hardening quality of a casting, by means of a chilled cast-iron mould, was improved in proportion as the silicon decreased. From the year 1878, in view of attenuating the elimination of silicon which occurred in the fusion of cast iron in the Siemens furnace, it was usual at Terre-Noire to add some ferro-silicon at the moment of running the cast iron into the moulds. This was an older practice than was supposed.

The general publication of those facts, and their collection into a connected system, required many years of experience and study. Mr. Hadfield had quoted the names of those experimenters whose work had contributed to throw light on that most interesting question. Mr. Pourcel would add that Mr. Hadfield's own work would not be the least distinguished.

Mr. H. A. BRUSTLEIN (Unieux), having been obliged to quit Paris before Mr. Hadfield's paper came on for discussion, was unable to take part in its consideration, as he would have liked to do. The knowledge of the influence of silicon on steel had, however, been advanced by investigations of older date than those cited by Mr. Hadfield. Among these he would notably refer to the works of Mr. Wenzel Mrázek, Professor at the School of Mines at Pribram, in Bohemia, who made a series of investigations on the alloys of—

1. Iron and silicon.
2. Iron, carbon, and silicon.
3. Iron, silicon, carbon, and manganese.

The remarkable work of Mr. Mrázek was worthy of being translated into English. It had already been published in the *Berg-und-Hüttenmänn. Jahrbuch der K. K. Bergkademie zu Pribram, Jahrgang XX.* From that period the researches of Mr. Mrázek had given some useful hints to those who were practically engaged in working upon this matter. Although silicon in steel was considered by some as a friend, and by others as an enemy, it was still an enigma to the man of science, and the practical steel manufacturer was not always permitted by his circumstances to furnish all the elements that would be likely to contribute to the elucidation of the problem.

Mr. W. J. KEEP remarks that the author had referred to Mr. King's diagram showing that a decrease of silicon changed grey iron to white. As contributing similar information, he referred, in an article about to be published by the American Institute of Mining Engineers, entitled "Phosphorus in Cast Iron," to engravings in Table II. showing the change of grain, where, owing

to oxidation due to six re-meltings, silicon was reduced from 1·16 per cent. to 1·04 per cent., and the grain was changed from dark to a very light grey.

In a second set of six tests, when, by additions of wrought iron, the silicon was reduced from 1·20 to 0·92 per cent., the grain changed from dark to perfectly white.

In the first series the strength increased slightly. In the second the strength increased very rapidly with each addition, until, at the sixth melting, it was nearly 70 per cent. greater than the initial grey iron.

In Table I. of the same paper, engravings were shown of the fracture of test-bars of white iron treated in the same way.

The re-melts began with a white iron, slightly porous, with 0·25 Si, and ended at the sixth melt, with a casting full of blow-holes and 0·12 Si.

Beginning with the same 0·25 Si white iron, wrought iron additions brought silicon down to 0·11 at the fifth heat, the casting being completely honeycombed. The iron was too sluggish to run the sixth heat. In both these series the strength rapidly decreased owing to blowholes.

The author had also referred to the experiments of Mr. Pourcel regarding the insolubility of silicate. A couple of years ago, Mr. Keep combined a grey pig iron having Si 1·249 and Mn 0·187 with a ferro-silicon having its Si 10·63 and Mn 2·52, making seven independent casts, which Mr. Fleming found to contain—silicon 1·24, 1·49, 2·03, 2·76, 3·46, 4·30, and 5·37; and Mn must have run up to about 1 per cent. in the last. The drillings from each of the casts were perfectly soluble.

Mr. Keep remelted each of these casts, producing a series with silicon 1·25, 1·73, 2·08, 2·77, 3·49, 4·54, and 5·55. Mn was not determined in the re-melts, but it probably had nearly disappeared.

Mr. Fleming stated: "After all the iron is dissolved and the carbon burned out, the $SiO_2$ (from oxidation of Si) retained exactly the shape of the drillings. This did not occur in the first melts, but only in the re-melts."

As a matter of curiosity, Mr. Keep would state that the strengths of each of the first casts, and of their re-melts, were

substantially alike, and yet each series showed results exactly contrary to those reported in his papers on the action of silicon before the American Institute, *i.e.*, each cast decreased in strength until 2·75 Si, when it was 12 per cent. weaker than at first, but increased in the next three casts, until, at the last, the strength was 55 per cent. greater than the first cast. This was an example of the way that chemical combination, or, more likely, mechanical structure, due to some unexplained cause, often surprised us in practice.

Mr. HARRY S. FLEMING (of the Cameron Iron and Coal Company, Emporium, Pa.) states that in regard to the re-melt, viz., silicon 1·25 to 5·55, he found that, using Drown's method of solution of drillings in dilute nitric acid, evaporating with dilute sulphuric acid and solution in water, and filtering and igniting to burn off the carbon, the resultant silica retained perfectly the shape of the drillings, was pure white, and completely volatilised by hydrofluoric acid. These silica skeleton drillings were examined under a microscope, and found to be a mass of minute crystals, but they were too small to show the form of crystallisation. Mr. Fleming thinks it possible that by re-melting an iron the silicon will gradually leave the combined form and assume the graphitic one, or be oxidised to silica, at least partially. Is there any proof that silicon, as such, is contained in steel, or in any metal which has been exposed to strong oxidising influences? In some experiments which he had been making, he had found only traces of silicon, while he had found as high as 1·23 per cent. of silica in some Bessemer steels.

Mr. T. TURNER (Mason College, Birmingham) regretted that he was unable to be present at the reading of the interesting and important paper presented by Mr. R. A. Hadfield. He had, however, been fortunate in seeing a number of the samples while the experiments were in progress, and in obtaining specimens for preservation in the collection at Mason College. The result of Mr. Hadfield's researches, while confirming a number of his (Mr. Turner's) observations, and very greatly extending our knowledge, showed, at the same time, the great importance of

conducting experiments, not merely with one kind of metal, but with all the varieties of iron and steel in general use. It was, of course, unnecessary to enter into details with regard to the differences in the influence of silicon when present, on the one hand, in cast iron, and, on the other hand, in wrought iron or steel. It would be sufficient to say that, in a number of important respects, the effect was entirely dissimilar in the two cases. But even with basic metal, before and after the addition of ferro-manganese, the presence of silicon produced physical characteristics which were different in certain respects in the two cases, and each of which again differed somewhat from the observations of Mr. Hadfield with crucible metal. Thus, it was noticed that, with basic steel to which no manganese had been added (and which contained only from 0·06 to 0·10 per cent. of manganese), the presence of silicon produced a perceptible red-shortness, for while ingots containing less than about 0·2 per cent. of silicon rolled moderately well, all ingots with a larger amount of silicon crumbled to pieces under the rolls. But after the addition of ferro-manganese (when the metal contained from 0·48 to 0·66 per cent. of manganese), all the specimens rolled well, and did not exhibit the least sign of red-shortness, even with as much as 0·5 per cent. of silicon In Mr. Hadfield's experiments, the first sample contained only 0·14 per cent. of manganese, and this ingot forged only "fairly well," while all the others, which contained from 0·21 to 0·36 per cent. of manganese, forged "very well," and gave no indication of red-shortness. Hence it would appear possible that with about 0·14 per cent. of manganese there was what may be termed a critical point; with less manganese even a little silicon rendered the metal red-short, while with more manganese even 5 per cent. of silicon might be present without preventing the ingot from forging. It was interesting to notice that in all three series of experiments it was observed that silicon increased the elastic limit and the tensile strength of the metal, and that ultimately the ductility was decreased, though this latter property was injuriously affected earlier in Mr. Turner's experiments than in those now published.

One interesting point brought out by Mr. Hadfield was the fact that silicon did not, when alone, confer upon steel the property

of hardening when it was heated and afterwards rapidly cooled. This point had been considered doubtful for some time past, though perhaps the general opinion had been in the opposite direction, due probably to the fact that when carbon and silicon occurred together in a sample of steel, the metal could sometimes be more readily water-hardened than if carbon only were present. Probably the greatest difference in the conclusions arrived at as a result of the several series of experiments was in connection with the influence of silicon on the weldability of the metal. The specimens examined by Mr. Hadfield were all deficient in this respect, while those prepared by himself (Mr. Turner) all welded well, except when, owing to a deficiency of manganese, the metal was red-short. No special care was taken by the smith in producing these welds, the specimens being given to him in the ordinary way, to be treated in exactly the same manner as the hundreds of other tests he would perform in the course of the year. The bar was then nicked and broken across the weld, and the fracture carefully examined. The tests were performed under the superintendence of Mr. Harbord, who has had special experience of such work, while all the samples were preserved, and had been recently re-examined. So that he (Mr. Turner) could not think that the weldability of ingot iron in any way suffered from the presence of silicon. It should be mentioned, however, that the highest amount of silicon added was only 0·5 per cent., and that the original metal itself welded perfectly.

The value of a series of experiments so complete and carefully conducted as those of Mr. Hadfield could scarcely be over-estimated, and it was much to be desired that those interested in the manufacture of iron and steel might soon be furnished with information with regard to all the other important elements as complete and as trustworthy as we now possessed in the cases of manganese and silicon.

Mr. CHARLES WOOD remarks that he listened with much attention to the paper read by Mr. Hadfield at the Paris meeting, and regretted that the time did not allow of a more extended discussion. He thought Mr. Hadfield had not given sufficient credit to the paper read by himself (Mr. Wood) at the Glasgow meet-

ing in 1885, because although, as he had then fairly stated, Mr. Turner had previously read a paper before the Chemical Society upon the effect that silicon had upon pure iron, it was then clearly announced for the first time by him (Mr. Wood) that in a series of experiments conducted in the foundry of Messrs. Wilson, Pease, & Co. Middlesbrough, by him, with the able assistance of his friend, Mr. Stead, the discovery was made that silicon had the power of reducing the combined carbon into uncombined carbon, or, in other words, to convert white iron into grey iron. And this had been fully admitted by M. Gautier, in a paper read at a meeting of the Iron and Steel Institute in the following year, in which he said, "This is an entirely new departure in metallurgy—the practice of most iron-founders having been based on a totally different view," and added that in his opinion "the discovery is perhaps of more importance than that of the basic process itself." Mr. Wood considered the investigation of M. Gautier as to the cause of this remarkable chemical change of the greatest scientific value. The experiments carried out at numerous foundries in France had completely established that fact, and confirmed the statements made by Mr. Wood at Glasgow. All the experiments made by Mr. Turner and Mr. Keep as to the power that silicon possessed to soften foundry castings had taken place since that time.

The practical value of this discovery had been as remarkable as it had been successful. Hundreds of iron-founders were now using a harder, and consequently a cheaper, class of iron in their cupolas, producing castings of better quality, being softer, stronger, finer on the skin, free from blowholes, contraction, or drawing, and, what was of equal practical importance, at less cost than before. Hard small scrap iron, which hitherto could not be used, and was considered bad, could now be made, by the proper use of silicon iron, into the finest and strongest castings.

The custom of purchasing irons by their fracture, in order to obtain sound castings, was a great mistake, and must be abandoned. Mr. Wood admitted that hitherto it had been the only practical system known, and that founders, in order to make soft castings, had always gone to Scotch No. 1, or like rich brands, to mix with other qualities in order to produce this result; but he

had shown that the commonest iron, such as mottled and white, could be reduced to any degree of softness by the proper mixture of silicon iron; and an iron-founder, by following this rule, and studying analyses of the irons at his command, could now produce in his cupola the exact quality of iron most suitable to his castings, instead of, as hitherto, depending upon special and expensive brands, which were often very uncertain in producing what was required, although the fracture might be all that was desired, whilst the only explanation was to be found by analysis. The fact that the firm that he had the honour to represent (Messrs. Wilson, Pease, & Co.) had made, and continued to make, many thousands of tons of silicon iron, which, prior to this discovery, was put back into the blast furnace, was a sufficient proof that both the theory and the practice were sound, and that ironfounders were daily leaving the old practice for the new.

Mr. Wood would merely add that, however interesting the information collected together by Mr. Hadfield—for which they were greatly indebted—and however valuable the experiments made by Mr. Turner and Mr. Keep, he found nothing new, or of any practical value to the ironfounder, which had not been already published. At the same time, these experiments, along with those of M. Gautier, had so completely confirmed the scientific rule and discovery first announced and laid before the Iron and Steel Institute at the Glasgow meeting, that there could not be any further doubt about it. And this had been more than once acknowledged in the able addresses of the late President of the Institute.

Mr. R. A. Hadfield, in reply to the correspondence, said he was glad to read the interesting contributions from American friends, Messrs. Keep and Fleming.

He much regretted the omission of reference to Messrs. Wood's and Stead's work in connection with the application of silicon to cast iron. His (Mr. Hadfield's) paper was, however, written principally as regards alloys of iron and silicon, not alloys of cast iron and silicon. The paper only referred to the latter when bearing upon the points under consideration. It was in no way intended as help to an ironfounder—Messrs. Turner, Wood, Stead,

Gautier, and Keep had done that—but it did deal with alloys of iron and silicon in such a way as to clearly establish the influence of the metalloid silicon upon the metal iron, a question hitherto in doubt.

M. Osmond, of Paris, was giving much attention to experiments upon samples of this steel furnished by the author, and important discoveries had been made which, no doubt, M. Osmond will shortly be able to lay before the Iron and Steel Institute.

The following paper was then read:—

# A NEW FORM OF SIEMENS FURNACE, ARRANGED TO RECOVER WASTE GASES AS WELL AS WASTE HEAT.

By JOHN HEAD, F.G.S., M. Inst. C.E., London,

AND

P. POUFF, Ingénieur des Arts et Manufactures, Nevers.

Before referring to the special subject of this communication, and in order that it may be the better understood, it is necessary to call attention very briefly to the great advance which has been made in heating and metallurgical operations, as the result of the labours of the late Sir William Siemens and of Mr. Frederick Siemens in connection with the regenerative gas furnace.

The first idea of applying the regenerative principle for industrial purposes appears to have occurred to the mind of the Rev. Robert Stirling in 1817, who, with his brother, James Stirling, invented a regenerative air engine, since bearing their name, which worked economically at the Dundee Foundry, and was found to be quite as efficient as the steam-engines of that day. They also foresaw the possibility of applying the regenerative principle to metallurgical furnaces. A more complete form of furnace of the same kind was devised in 1837 by Mr. J. Slater. According to this arrangement, as well as in the earlier form proposed by the Stirlings, only the air supplied to the furnace was to be heated, and solid fuel was intended to be employed. Neither of these proposals, however, led to any practical result, so that they can only be looked upon as mere philosophical ideas or suggestions. The same remark applies also to the later proposal of Mr. R. Laming, who, in 1847, took out a patent for a regenerative furnace embodying the then novel principle of first converting solid fuel into gas, to be burnt in a furnace in combination with air heated by means of the waste products of combustion. This was a further step in advance in furnace construction; but as Laming's invention was proposed for heating gas retorts, and coke was in consequence the fuel intended to be

employed, the attainment of only a relatively low temperature was contemplated.

By the light of present knowledge, it is clear that none of these proposals were susceptible of useful application without considerable modification, and there is no evidence of any application of these furnaces having been made before the Siemens furnace was introduced; in fact, it is only recently that the existence of these earlier proposals to apply the regenerative principle to furnaces has been made known; and in spite of them, or perhaps on account of these proposals never having been carried out, Mr. Frederick Siemens and the late Sir William Siemens will ever be regarded as the true inventors of the regenerative gas furnace. They were the first to show, by means of philosophical reasoning, what really could be effected by the application of the regenerative principle to furnaces, and having a clearly defined idea in their own minds of the capability of the valuable apparatus with which they were dealing, they perfected that wonderful invention which may justly be said to have revolutionised the construction of furnaces for high temperatures.

Messrs. Siemens were the first to heat the gas as well as the air supplied to a furnace, utilising its waste heat for that purpose, and to provide for reversing the direction of the flame in the furnace chamber whereby uniformity of heat and the highest temperatures are attained. They thus rendered possible the carrying out of processes which, until the introduction of their furnace, had only been foreshadowed by chemical research. The great economical idea embodied, and carried out in the regenerative gas furnace, is perhaps best illustrated by comparison with such a meritorious invention as Neilson's Hot Blast Stove. In this case the temperature of the blast was raised by means of fuel separately burned for that purpose, but in the case of the Siemens Regenerative Gas Furnace, the heat below the temperature of the work carried on in the furnace is impounded in the regenerators, and applied to heat up the gas and air supporting combustion. In high temperature furnaces, the heat below the temperature of the work to be performed therein is by far the largest proportion of the total heat produced, and previously to the introduction of the Siemens Furnace, this heat had been lost by being allowed to pass away with the waste gases to the chimney. This circum-

stance was clearly explained by Lord Armstrong at the Meeting of the British Association at Birmingham in 1865. By heating the inflowing gas and air, the temperature of the flame in a furnace may be raised to almost any extent; in fact, the heat attainable under these conditions, is only limited by the power of resistance of the materials of which the furnace is built, and thus the highest temperatures required in metallurgical operations are obtained with facility by the expenditure of a moderate amount of fuel, especially since the introduction by Mr. Frederick Siemens of the method of heating by radiation, by which means the durability of the furnace has been also much increased.

In considering the details of construction of this ingenious apparatus, it occurred to Mr. E. Biedermann and Mr. E. W. Harvey, who are on Mr. Frederick Siemens' technical staff (the former having entered the service of the late Sir William Siemens about thirty-four years ago), that possibly further economy in fuel might be realised by a re-arrangement of some of the parts of the regenerative gas furnace. Their attention was directed to the conversion of solid fuel into gas in the producer, and to the relatively high temperature at which the products of combustion passed from the furnace into the regenerators, as also to the chemical composition of these products, which temperature and gases they thought might be utilised in the gas producer.

In an ordinary gas producer the production of carbonic oxide is effected in two operations; on the grate hot carbonic acid is formed, in the ordinary course of combustion, and this carbonic acid is afterwards converted into carbonic oxide by taking up another equivalent of carbon, whilst passing through the incandescent fuel in the upper portion of the producer, and in that condition it flows on to the furnace with the other gases distilled from the coal during the process of gasification. It should be remembered, however, that the production of carbonic acid on the grate of the ordinary gas producer is attended with the development of heat; whereas the conversion of carbonic acid into carbonic oxide, in the upper portion, is carried on at the expense of heat.

In the new Siemens furnace, the gaseous products of combustion from the heating chamber of the furnace are delivered under the grate of the producer, these gases consisting of intensely hot carbonic acid, water in the gaseous state, and nitrogen, the

production of carbonic acid in the producer may be therefore dispensed with; but in this case the heat attending the production of carbonic acid in the producer has also to be dispensed with. It had therefore to be ascertained whether the products of combustion from the heating chamber would contain a sufficient amount of heat for insuring their conversion into combustible gases. This has been found to be the case in practice with furnaces working regularly for the past six months—a satisfactory result that is probably due to the presence of a large quantity of heated nitrogen in the products of combustion, which, passing through the producer without undergoing chemical alteration, maintains the heat of the fuel. The economy of fuel resulting from the conversion of carbonic acid into carbonic oxide is diagrammatically illustrated by means of the accompanying sketch (fig. 1) of a gas producer. Assuming that the producer contains only coke in the incandescent state, this coke if fed with oxygen will produce carbonic acid in the lower zone, which will be converted into carbonic oxide in the upper zone; but if fed with hot carbonic acid, instead of oxygen, one half the fuel, comprising the lower zone, may be dispensed with, and an economy in weight ot fuel to the same extent will be realised.

The furnace about to be described must be clearly distinguished from that form of regenerative gas furnace before referred to as having been first suggested by Mr. R. Laming in 1847, where conduction air regenerators alone are employed. The latter form of furnace is necessarily wasteful in working, inasmuch as in theory it can only utilise about one half of the total heat contained in the gases leaving the furnace chamber, this being the ratio of the air for combustion to the amount of gases made from coal entering the furnace, and in practice it would fall short of this saving, owing to the class of regenerator employed, in which the heat from one current to another had to be transmitted through brickwork. In the new Siemens furnace, on the contrary, the waste gases are directed, partly through an air regenerator, and partly under the grate of the producer, there to be reconverted into combustible gases, and to do the work of distilling hydro-carbons from the coal; in fact, the gas producer in this case absorbs or utilises the heat formerly deposited in the gas regenerators of furnaces; and in doing this transforms spent gases into combustible gases.

*

It is held as an axiom, and the construction of the new furnace is based upon this consideration, that, besides air regenerators, gas regenerators, or their equivalent in the form of a converter producer, must be provided for absorbing all the heat contained in the gases leaving the furnace chamber. In the converter, the fuel absorbs the waste heat from a portion of the products of combustion leaving the furnace, and at the same time carbonic acid and water-vapour are converted into carbonic oxide and hydrogen. Disregarding the small proportion of water-vapour they contain, the products of combustion from a furnace may be taken as consisting of—

$CO_2$, 17 per cent.; O, 2 per cent.; N, 81 per cent.

The 17 per cent. of $CO_2$, also the 2 per cent. of O, are converted into CO, whilst the nitrogen simply passes through the fuel without change, and serves the useful purpose of maintaining its heat for the conversion of the other gases.

For the propulsion of the gases through the converter, a steam blast is employed. This steam is superheated by the waste gases from the furnace, and, mixing with them, forms a very hot blast indeed under the grate. The diagrams (figs. 2 and 3) show the relation which exists between the ordinary and the new type of Siemens furnace. As will be seen by examining them, the function in both is the same. In the first case, the waste gases are partly directed through two regenerators, while, in the second case, the waste gases are partly directed through an air regenerator and partly through a converter producer. In both cases the waste heat from the furnace is entirely utilised, and the gas and air reach the furnace in an intensely heated condition. In both cases, again, there is a reversal of the direction of the flame in the furnace, which ensures uniform heating of the furnace chamber and the materials contained in it.

This furnace may be constructed in various forms, the one shown in the accompanying diagrams (figs. 4–8) having been used with success for heating and welding iron. It is a radiation furnace, heated by means of a horse-shoe flame; this form of flame offers advantages in this as in ordinary regenerative gas furnaces, but its adoption is not obligatory, as the flame may be made to traverse the heating chamber from end to end in the usual

manner. The same letters indicate the same parts in all the figures. AA' are reversible regenerators for air, on the top of which is built the gas producer or converter B, of which FF' are the charging hoppers and NN' the grates. The heating chamber E adjoins the producer resting on the ground, or in some cases a pit may be provided below it. CC' are the flues leading the combustible gas to the furnace chamber E, the passage of the gas in these flues being controlled by the valves DD' at the two ends of a rocking-beam, so that the outlets are opened and shut alternately to convey the gas to one or other of the ports GG' of the heating chamber E. HH' are the air ports of the heating chamber, communicating through the flues KK' with the regenerators AA'. II' are steam jets placed in the return flues for directing a portion of the waste products of combustion to the grates of the converter. J is the valve for reversing the direction of the air flowing into the furnace, and of the products of combustion through the regenerators to the chimney flue. OO' are hinged caps for alternately admitting and shutting off the products of combustion from the heating chamber to the converter. These caps are worked automatically by means of connections attached to the rocking beam, the same movement which closes D opening O', and that which closes D' opening O. Qq are doors for giving access to the grates of the converter for clearing them.

The *modus operandi* of the furnace is as follows:—Gas from the converter B passes through the flue C' and the valve D' to the gas-port G', and into the combustion-chamber *h' g'*. Air for combustion passes through the regenerator A', the air-flue K', and the air-port H' into the combustion-chamber, where it meets the gas from the converter, and combustion ensues. The horse-shoe flame sweeps round the heating-chamber E, the products of combustion passing away by the second combustion-chamber *h, g,* and going partly through the regenerator A, and reversing valve J into the chimney-flue, and partly down the flue G, whence they are drawn by means of the steam jet I through the capped inlet under the grates NN' of the producer B, there to be converted into combustible gases. From time to time the direction of the flame in the furnace is reversed by manipulating the rocking beam, carrying the valves DD', and the reversing valve

J in the usual manner of working regenerative gas furnaces. An auxiliary steam jet is provided for the purpose of supplying atmospheric air to start the producer, when the furnace is first heated up.

The new form of regenerative gas furnace has been applied in this country to the heating and welding of iron, to which uses its application is being extended in England and abroad, whilst furnaces are in course of construction to apply it for puddling iron, and for copper and steel melting. Altogether ten furnaces for these purposes are in course of construction, in addition to two furnaces already at work for heating iron.

The first furnace of this kind was constructed at the Pather Iron and Steel Company's Works at Wishaw for welding iron, and much credit is due to the proprietors for having had the enterprise and public spirit to make the first application of this improved regenerative gas-furnace. The working has been eminently satisfactory from the commencement. The success of this first application of the furnace proves the correctness of the principle upon which it is constructed, and the means adopted for carrying it out.

The results of working during the past six months have shown an average saving of 5 per cent. in waste on the weight of the iron heated, and a saving of upwards of two-thirds of the weight of coal used, and a greater money-saving, owing to the inferior quality of the fuel employed as compared with that used in their other furnaces fired with solid fuel. From the total saving thus realised should, however, be deducted the cost of raising steam, for which purpose the waste heat of the old furnaces is utilised. Allowing for separate boilers, the saving effected by the use of the new system in a furnace heating eight tons of iron per shift, is nearly eighteen tons of coal per week, and the money-saving in iron and coal exceeds £1000 per annum.

This new furnace has also been recently applied for heating billets by the United Horse Shoe Company, of London, and in this case the results are quite as satisfactory, or even better, than those just given, as is shown by the accompanying table:—

*Results of Heating Billets by New Siemens Furnace.*

| e. | Number of Charges per Shift. | Duration of each Shift. | Average Time required for Heating to Welding. | Weight of Billets Heated. (30″ × 2¼″ × 2¼″.) | Coal. | | |
|---|---|---|---|---|---|---|---|
| | | | | | Weight Used. | Used per Ton of Billets. | Quality. |
| ). | | A.M. P.M. | Minutes. | Tons. Cwts. | Cwts. | Cwts. | |
| . 13 | 11 | 5·45 to 5·25 | 21 | 8 16 | 17½ | 1·9 | Newcastle small. |
| . 14 | 6 | 6·0 to 12·15 | 20 | 4 16 | 8 | 1·7 | Newcastle cobbles. |
| . 16 | 11 | 5·45 to 5·30 | 21 | 8 16 | 17¾ | 2·01 | ⅚ Newcastle small. ⅙ London screenings. |
| . 17 | 11 | 5·45 to 5·30 | 26 | 8 16 | 18¼ | 2·08 | London screenings. |

t will be noticed from these results that in this furnace eleven 'ges are made in less than twelve hours, each weighing about :wt., and yielding in the finished state as horse-shoe iron 15 per charge, or 8·25 tons in the day. The amount of small used was about 18 cwts. per shift. This is equivalent to $\frac{18}{8\cdot8}$ = rts. per ton of iron heated, which, it will be admitted, is a t satisfactory result; in one case the consumption of coal was ı reduced to 1·7 cwt. per ton, each billet coming out at a welding heat and rolling into a sound bar. The coal used ı day is indicated in the table.

'he following are analyses of gas made in the converters at ıer and in London respectively :—

| Pather Co., *from Wishaw Coal (nuts).* | | United Horse-Shoe Co., *Newcastle Cobbles.* | |
|---|---|---|---|
| $CO_2$ | 4·6 | $CO_2$ | 4·5 |
| ) | nil | O | nil |
| CO | 23·0 | CO | 22·5 |
| I total | 17·4 | H | 16·3 |
| ) vapour | 1·5 | $CH_4$ | 2·6 |
| I | 53·5 | N | 54·1 |
| | 100·0 | | 100·0 |

'rom these analyses it will be seen that the proportion of in the gas made in the converters is not greater than that le in the ordinary Siemens producer.

Besides the advantages in the saving of fuel and metal, it is rable to call attention to the simplicity of design of the new ace, owing to which its cost of construction is not much ter than that of a solid-fuel furnace, while its cost of mainınce is very much less. The cost of construction of the new ace is found to be about two-fifths of that of the old form of

regenerative gas furnace, of the same productive capacity, with separate gas producers and gas regenerators, and the space occupied below ground is also considerably reduced.

A saving of labour attends the employment of the new furnace, as, owing to the producer being connected with the furnace, the same men can attend to both, and the labour of firing is reduced in proportion to the reduced consumption of fuel.

In conclusion, the following advantages may be claimed for the new furnace as compared with solid-fuel furnaces used for heating and welding iron, viz.:—

A saving in fuel, amounting to, say, two-thirds in weight, and after allowing for raising steam in separate boilers, this saving is fully equal to 5 cwt. of coal per ton of iron heated.

A reduction in the waste of iron equal to 5 per cent. upon the weight of metal heated.

A saving in labour and repairs which will probably compensate for the extra cost of the new furnace.

Taking a furnace to heat 10 tons of iron per shift, or 110 tons per week, the following calculation gives the money saving realised by the adoption of the new furnace:—

| | | | |
|---|---|---|---|
| 110 tons iron at 5 cwt. per ton = 27½ coals saved at 6s. . . . | £8 | 5 | 0 |
| 110 „ „ at 5 per cent. = 5½ tons iron at £4 . . . . . | 22 | 0 | 0 |
| Being . . | £30 | 5 | 0 |

per week, or say, £1500 per annum.

It may be added that the authors had hoped that the application of this furnace to the attainment of high temperatures, such as are required for steel melting, might have been included in the paper, but the furnaces building for this purpose are not yet completed. Should they, however, be working when the paper is read, information with regard to them will be given in the discussion.

## *DISCUSSION.*

The PRESIDENT said it would be a great advantage to have the discussion on the paper postponed until the London meeting, because they would then, probably, have before them the experience of the ten or twelve furnaces now building. It occurred to him to remark that the proposed arrangement appeared to solve the difficulty, and to remove the objection of Sir Lowthian Bell as to the cooling of the gases. They had the direct application of the gases to the material, and it was an admission, to a certain extent, that there was a loss in the cooling of the gases. The arrangement appeared to him to be a most admirable one. The only question he wished to ask Mr. Head was, whether he had any difficulty in passing the flame through the whole body of the furnace? It appeared as if there would be a difficulty in the flame reaching the doors.

Mr. HEAD said that there was no difficulty experienced in getting the heat to the doors in the horse-shoe flame furnace shown by the diagrams.

The PRESIDENT said the subject was one of great interest. He was sure that they would all be satisfied, from the reputation of Messrs. Siemens and the authority with which they treated the subject of furnaces, that the matter was one that ought to receive the careful attention of those who had large masses of iron to heat. He had great pleasure in proposing that the thanks of the meeting be given to Mr. Head and to Mr. Pouff for their paper.

The motion was unanimously adopted, and the following paper was next read:—

# THE ROBERT-BESSEMER STEEL PROCESS.

BY F. LYNWOOD GARRISON, PHILADELPHIA.

THE history of this modification of this ordinary Bessemer process dates back to about the year 1884, when what was then known as the Walrand-Delattre converter was put into practical operation at the Stenay Works, Meuse, France. This converter having already been described,* it will be sufficient to simply call attention to the above fact.

The converter at present used at Stenay, and known as the Robert converter, is shown in figs. 1 and 2. It is used either with an acid or basic lining, as desired.

It has a distinctly elliptical shape, having a flat surface P in which the tuyeres "a" are always placed on the same plane parallel to the axis XX of the apparatus. It has a swinging movement on its trunnions X'X', supported by suitable bearings. This movement can be imparted by means of any suitable mechanism; for instance, by that clearly shown in the drawings, and the effect is that the range of tuyeres can be simultaneously disengaged from the metal bath.

The tuyeres, placed horizontally, as described, form, with the flat surface P, unequal angles varying with the shape of the transverse section of the apparatus, with a view to impart a rotary motion to the bath, which brings all parts of the metal bath successively under the oxydising influence of the blast. This movement causes a regular and methodical rotation of the bath, so as to prevent too prolonged a period of decarburization of each portion of the metal.

As soon as the metal is run into the converter, it is tilted up until the metal comes to the level of the tuyeres, and the blast is turned on (fig. 3).

By the action of the blast through the range of tuyeres inclined at different angles a rotary motion is gradually imparted.

When this movement, which is indicated by the spiral move-

* *Iron Age*, vol. xl., No. 10; *Journal*, No. II., 1887, p. 314.

ment of the sparks at the mouth, is clearly marked, the apparatus is gradually raised, but it is claimed, owing to the pressure of the blast, that the bath does not attain a horizontal position, as at fig. 4; but that the surface becomes inclined and assumes the position indicated in fig. 5.

The molecules of metal are thus successively brought under the influence of the blast. The slag and gases, by reason of the difference in their density, become separated from the metal, which separation is supposed to be facilitated by the rotary motion.

By reason of the position of the tuyeres, only a portion of the air introduced at the constantly renewed surface of the bath reacts upon the carbon in the iron, forming carbonic oxide.

This carbonic oxide, rising in the converter, at once comes in contact with an excess of air, producing carbonic acid and a great generation of heat. The blast being introduced obliquely, an intimate mixture of the gases occurs, and the combustion takes place at the very surface of the bath, producing a maximum temperature at that point.

At the beginning of a blow, the pig iron is run in either from a ladle or directly from the cupola. In the latter case, the period at which the surface of the metal arrives at the level of the tuyeres is ascertained by the change of sound which the blast produces in the apparatus. This period can also be ascertained by observing the sparks which are given out at the commencement.

When the level of the bath is about an inch below the tuyeres, the blast valve is opened. The action of the blast is only felt at this moment by a very small portion of the metal on the side opposite the tuyeres, which is atomised, causing a considerable rush of sparks. The apparatus is gradually raised, and the sparks diminish as the greater portion of the air slips over the surface of the metal. When the molten iron arrives at the level of the tuyeres, the noise made by the blast becomes duller, and the sparks increase, because the air penetrates a thin layer of the molten metal. At this moment the blast must be stopped, that the "*lighting*" may be done properly. When the sparks diminish and change their colour, the apparatus must be gently raised until the flame begins to issue from the mouth. In this position the converter is stopped and the flame allowed to issue. It is only when it is well alight

that the apparatus must be further raised, until it arrives at a position where, if the blast were shut off, the tuyeres would be covered by about $1\frac{1}{2}$ in. to 2 ins. of metal.

It is easy to understand that by tilting the converter more or less, and by manipulating the blast valve, the operator can at will change the volume and pressure of the blast to correspond with the requirements of the different phases of the operation.

It is of great advantage to be able to control the pressure of the blast so as to regulate it at the different periods of the operation, and in proportion to the quantity of the charge in the converter.

The resistance to the blast may be varied by tilting the converter more or less on one or the other side, and as the tuyeres have all the same height of metal to support, the pressure on each tuyere is consequently the same.

It is obvious that the blast pressure required is much less than in the ordinary Bessemer converter. A converter which has the tuyeres at the bottom will require a much higher pressure of blast than one which has its tuyeres at the sides.

In an ordinary Bessemer converter, the height of the iron above the tuyeres is the entire depth of the metal, and in the "Robert" converter it is only about from 10 to 15 centimetres; the result is, that an economy of blast force is obtained for the same quantity of iron.

The average pressure of the blast is about 4 lbs., the aim being to have just sufficient pressure to keep the slag "*out of the metal*," and to produce the rotation of the bath. In no case should the blast penetrate deeply into the bath; it must only impinge upon its surface.

The first period of the blow lasts from seven to eight minutes, the second from three to four. At the end of the second period the flame disappears, and it might be supposed that the carbon has been eliminated. The blow, however, is continued during a third period, lasting from one and a half to two minutes, in which the flame reappears, and is of considerable size. As a rule the blows are quiet. As soon as the flame drops, after this third period, the converter is turned down and about one per cent. of seventy per cent. ferro-manganese added. The converter is then allowed to stand about ten

minutes to allow the ferro-manganese to melt and disseminate. If a basic lining is used, rather more ferro-manganese is required.

It may be added either to the metal in the converter, or after it has been poured into the ladle. If the addition has been made in the converter, and if the bath has been thoroughly deoxidised, the steel can be run off without any fear of its boiling over.

For the purpose of obtaining steel castings, some ferro-silicon may be added in the ladle, but it must not exceed 0·008 of ferro-silicon having 10 per cent. of silicon; a larger proportion would injure the quality of the steel.

The steel is run off directly from the converter into several small ladles, or a single large one, according as small castings, ingots, or large castings are desired.

The converters are mounted upon trunnions in the usual way, and revolved by hand, by means of the wheel and gearing shown in fig. 2. There is much room for improvement in the mechanical details of the apparatus, as some of the arrangements are very crude and awkward. Better results will doubtless be obtained with more improved mechanical appliances. The converters are all small, in no case exceeding three tons capacity, but I am informed that in America 5-ton converters have been successfully employed.

*Acid Linings.*

These can be made either of bricks or of composition. In both cases the materials employed must be highly refractory, by reason of the high temperature within the converter. They should not be too friable, as they must resist the shocks caused by the movement of the metallic bath. The bricks employed in the construction of an acid lining should be highly silicious, and contain as little lime and magnesia as possible. The following mean composition of bricks gives good results :—

| | Per cent. |
|---|---|
| Silica | 96·75 |
| Alumina and oxide of iron | 2·55 |
| Lime | 0·40 |
| Various | 0·30 |
| | 100·00 |

To construct the lining, a certain quantity of sand is first rammed down on to the bottom of the apparatus to make an even and hori-

zontal surface; above this are placed two layers of bricks, laid flat. The thickness of the sand and the bricks must be calculated so that the lining of the bottom is at least 10 ins. thick, and its upper surface 11½ ins. below a plane passing through the axis of the tuyeres. When the bottom is completed the lining of the sides is constructed.

Suppose we are dealing with a converter calculated to contain from 1000 lbs. to 3600 lbs. of pig iron. The mould is made in the following manner:—On the line AB (fig. 6), which represents the interior flat surface, a perpendicular DE is erected. On this perpendicular, from the point D, a distance DC is marked equal to 7¾ ins. From the point C as a centre, with a radius of 15½ ins., a circumference FKG is described, which represents the shape of the interior of the converter.

At the part corresponding to the mouth, the lining gradually diminishes until there is a thickness of one brick only.

If the converter is designed for a greater capacity than 3600 lbs., the interior dimensions of the lining will be increased without increasing too much the distance of the point K; that is to say, in proportion as the transverse section of the area increases the proportion $\frac{DK}{2CK}$ diminishes, and the curve CKF becomes semi-elliptical.

Fig. 7 shows the form and dimensions of the bricks suitable for a 1-ton apparatus; the bricks of the form A are for the curved portion of the lining; the bricks B are for all the other parts, the bottom, flat surface, &c.; 10 ins. is given as the length of the bricks A, but they can be made of a length equal to the thickness of the curved portion of the lining. The mortar used for the joints in acid linings must be very refractory. The cost of a brick lining is rather high. A skilled and careful workman is required to make it, otherwise the joints are not made close enough, and escapes occur. If clay sufficiently refractory, and capable of binding well when rammed, can be obtained, it is preferable to make the lining of composition. Its cost is much less than that of a brick lining, its construction is more rapid, it does not require special workmen, and it is more homogeneous.

We commence by lining the bottom to the desired thickness,

from 10 ins. to 11½ ins., taking care that the surface of the last layer is perfectly horizontal, and at a distance of 11½ ins. from a plane passing through the axis of the tuyeres. On this lining, carefully levelled, is placed the first mould, which in a 1-ton converter is half the height of the cylindrical part.

Fig. 8 shows the construction and the method of joining together the parts of the mould.

The clay is placed round this mould in successive layers of 1 in. in depth at most, and rammed down with rams heated to a red heat, shown at fig. 9. When the height of the tuyeres is reached, mandrils are inserted, and the ramming is continued.

Fig. 10 shows the lower part of the apparatus during the process of ramming.

When the top of the first mould is reached, a second similar mould is superimposed, and the ramming is continued to the joint of the mouth.

To facilitate the work at the mouth, this is removed and placed as shown at fig. 11.

### *Shape, Dimensions, and Disposition of the Tuyeres.*

Two kinds of tuyeres are used. 1. Burnt clay tuyeres. 2. Tuyeres made in the lining. Tuyeres of refractory burnt clay are always used for brick linings, and sometimes for composition linings.

The drawing, fig. 12, shows the shape and principal dimensions of a very convenient kind of tuyere. The shape *b* facilitates the work of the mason who constructs the lining; but the shape *a* is preferable, as it enables the tuyeres to be changed more easily and more rapidly.

The tuyeres are slightly conical in a longitudinal direction. This shape enables them to be withdrawn and to be replaced more easily. The axes of the tuyeres must be in the same plane, which is horizontal when the apparatus is in a vertical position. In a 1-ton apparatus the tuyeres are five in number, and disposed as shown in fig. 2. As will be seen, the angles of the tuyeres to a perpendicular on the flat surface are respectively about 0°, 5°, 10°, 15°, 20°. When the lining is of composition, the tuyeres are

disposed in the same way. Care must be taken to preserve the respective inclinations whilst ramming.

When the tuyeres are nearly worn out, the operation can be continued by doing the small necessary repairs every four or five blows. The apparatus is placed in the position shown at fig. 13, balls of mortar are thrown on the tuyeres, and they are beaten down with an iron peel or trowel. Holes are pierced in this mortar by means of a mandril of the diameter of the tuyeres, and it is allowed to dry for from fifteen to twenty minutes. With a 1-ton apparatus, and the arrangement of tuyeres above indicated, experience has proved that the best blast pressure on the tuyeres is from 3 to 4 lbs. per square inch. Below 3 lbs. operations are very lengthy and difficult to manage. Above 4 lbs. they are colder, last almost as long, and the waste is greater.

Whatever the pressure one may have at disposal, a regulating valve is necessary. When the capacity of the apparatus is increased, the number of tuyeres must be increased, but the blast pressure need not be appreciably higher.

The analysis of the pig iron used at the Paris works, 150 Rue Oberkampf, is as follows:—

| | Per cent. |
|---|---|
| Carbon | 3·50 |
| Silicon | 2·00 |
| Manganese | 1·00 |
| Sulphur | 0·05 |
| Phosphorus | 0·05 |

The resulting steel had a range of from 0·07 to 0·30 per cent. carbon, from 1·60 to 3·90 per cent. silicon, and about 1·00 per cent. manganese.

It is claimed for the process that the composition of the resulting steel can be regulated to a nicety. It is very doubtful, however, if it possesses any advantages over the ordinary Bessemer process in this particular.

Pig iron having a high percentage of silicon naturally causes a high temperature in the operation, but it has the disadvantage of materially increasing the waste. On the other hand, it is inadvisable to reduce the percentage below 1·4 in the pig iron at the cupola.

— the percentage of silicon is low, in order to obtain a high

temperature the period of decarburation is prolonged by uncovering the tuyeres, or rather decreasing the height of metal over the tuyeres, and thus diminishing the pressure of the blast.

Pig iron can be treated in the converter, either direct from the blast furnace, or after being remelted in the cupola. In both cases it is important that it should be very hot when run into the converter.

I was unable to obtain any analysis of the pig iron used in the basic-lined converters, but I was informed that pig iron of, or approaching, the following composition gave the best results:—

| | Per cent. |
|---|---|
| Sulphur | 0·04 |
| Manganese | 1·80 |
| Phosphorus | 2·00 to 2·50 |
| Silicon | 0·50 |

The ferro-manganese used contained manganese 71·10, phosphorus 0·01, and silicon 0·15 per cent. Ferro-silicon—silicon 10·00, sulphur 0·03, manganese 1·30, and phosphorus 0·003 per cent.

The *basic* lining consists of calcined dolomite, as free from silica as possible. After calcining, the dolomite is crushed, powdered, and mixed with 10 per cent. of coal-tar, absolutely free from water.

The lining of the sides and bottom of the converter is made of what is called the thin mixture. This mixture is generally made in bulk, in the proportion of one part of hot tar to four parts of dolomite. The mixture is first manipulated with a shovel on an iron plate, and is then introduced into a mixing apparatus in which the dolomite and the tar must be intimately mixed together. If the mixture is well made, it must not fall into powder when squeezed in the hand. It is absolutely necessary to keep the thin mixture free from any moisture.

Bricks can also be made of this mixture by moulding them under heavy hydraulic pressure. They will stand better than composition. The joints of these bricks are made of the same thin mixture.

To repair any damages or holes which may occur in the lining of the converter, a thick mixture is used, viz.:—

1½ to 2 parts of hot tar.
4 „ dolomite.

This thick mixture is much more dense than the thin; its composition in weight is about—

| | |
|---|---|
| Tar | 15 |
| Dolomite | 85 |
| | 100 |

The lime used must be free from moisture, and, like the dolomite, contain as little silica as possible. The composition of the resulting basic slag is about as follows:—

| | Per cent. |
|---|---|
| Silica | |
| Lime | 25·80 |
| Magnesia | trace |
| Oxide of iron | trace |
| Phosphoric acid | 16·00 |
| Sulphur | 0·17 |
| Manganese | 2·80 |

The amount of phosphoric acid varies from 15 per cent. to 25 per cent.

The following tables of tests of "Robert" steel were supplied by the Robert Steel and Iron Company (Limited), London. They are claimed to be average working results obtained at the Blaenavon works in England, and at the Stenay works in France.

BLAENAVON WORKS, TESTING-HOUSE.—*December* 14, 1888.

*Report on Tensile Tests of Basic Steel.*

| Marks and Numbers. | Materials. | Size of Specimen. | | | Maximum Strain. | | Breaking Strain. | | Elongation. | | Contraction of Area. | | Remarks. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Length. | Diam. | Area. | On Piece. | Per sq. in. | On Piece. | Per sq. in. | Stretched to | Per cent. | Diam. at point of Fracture. | Per cent. | |
| | | Ins. | Ins. | | Tons. | Tons. | Tons. | Tons. | Ins. | | In. | | |
| 1 | Robert tin bar | 2 | ·565 | ·25 | 6·25 | 25·00 | 5·12 | 20·5 | $2\frac{25}{32}$ | 39·00 | $\frac{23}{64}$ | 59·84 | Samples of tin bar made of Robert basic steel. |
| 2 | ,, ,, | ,, | ,, | ,, | 6·25 | 25·00 | 5·35 | 21·42 | $2\frac{13}{16}$ | 40·62 | $\frac{11}{32}$ | 62·88 | ,, ,, |
| 3 | ,, ,, | ,, | ,, | ,, | 6·47 | 25·89 | 5·35 | 21·42 | $2\frac{3}{4}$ | 37·5 | $\frac{11}{32}$ | 62·88 | ,, ,, |
| 4 | ,, ,, | ,, | ,, | ,, | 6·25 | 25·00 | 5·12 | 20·5 | $2\frac{13}{16}$ | 40·62 | $\frac{11}{32}$ | 62·88 | ,, ,, |
| 5 | ,, ,, | ,, | ,, | ,, | 6·02 | 24·10 | 5·12 | 20·5 | $2\frac{13}{16}$ | 40·62 | $\frac{11}{32}$ | 62·88 | ,, ,, |
| 6 | ,, ,, | ,, | ,, | ,, | 6·25 | 25·00 | 5·12 | 20·5 | $2\frac{25}{32}$ | 39·00 | $\frac{23}{64}$ | 59·84 | ,, ,, |
| 1 | Robert billets . | ,, | ,, | ,, | 6·69 | 26·78 | 5·35 | 21·42 | $2\frac{5}{8}$ | 31·25 | $\frac{23}{64}$ | 59·84 | Samples of billets made of Robert basic steel. |
| 2 | ,, ,, | ,, | ,, | ,, | 6·47 | 25·89 | 5·35 | 21·42 | $2\frac{45}{64}$ | 35·31 | $\frac{23}{64}$ | 59·84 | ,, ,, |

BLAENAVON WORKS, TESTING-HOUSE.—*July* 15, 1889.

*Report on Tensile Tests of Basic Steel.*

| Numbers. | Materials. | Size of Specimen. | | | Maximum Strain. | Breaking Strain. | Elongation. | | Contraction of Area. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Length. | Diameter. | Area. | Per sq. inch. | Per sq. inch. | Stretched to | Per cent. | Diameter at point of Fracture. | Per cent. |
| | | Ins. | | Sq. in. | Tons. | Tons. | Ins. | | In. | |
| 1 | Robert steel . . . . | 2 | Flat $1 \times \frac{3}{4}$ | ·375 | 25·00 | 22·61 | $2\frac{45}{64}$ | 35·31 | $\frac{3}{4} \times \frac{3}{16}$ | 62·40 |
| 2 | " " . . . . | " | Round ·565 | ·25 | 24·10 | 20·53 | $2\frac{27}{32}$ | 42·18 | $\frac{11}{32}$ | 62·88 |
| 3 | " " . . . . | " | " | ·25 | 27·67 | 25·00 | $2\frac{3}{4}$ | 37·50 | $\frac{3}{8}$ | 55·84 |
| 4 | " " . . . . | " | " | ·25 | 27·67 | 24·10 | $2\frac{3}{4}$ | 37·50 | $\frac{3}{8}$ | 55·84 |
| 5 | " " . . . . | " | " | ·25 | 28·92 | 25·00 | $2\frac{25}{32}$ | 39·06 | $\frac{11}{32}$ | 62·88 |
| 6 | " " . . . . | " | Flat $\frac{3}{4} \times \frac{1}{2}$ | ·375 | 25·82 | 22·61 | $2\frac{27}{32}$ | 42·18 | $\frac{7}{16} \times \frac{1}{4}$ | 70·83 |
| 7 | " " . . . . | " | " | ·375 | 23·80 | 19·07 | $2\frac{13}{16}$ | 40·62 | $\frac{7}{16} \times \frac{7}{32}$ | 74·48 |
| | | ... | ... | ... | 26·14 | 22·70 | ... | 39·19 | ... | 63·59 |

D. JONES.

*Average Analysis of the above Samples.*

Results of Experiments to Ascertain the Elastic and Ultimate Tensile Strength, &c., of Seven Pieces of Basic Steel Bar Manufactured by the "Robert" Process.

| Test No. | Description. | Original: Size. | Original: Area. | Stress: Elastic, per sq. inch. | Stress: Ultimate, per sq. inch. | Ratio of Elastic to Ultimate. | Contraction of Area at Fracture. | Stress per square inch of Fractured Area. | Extension, Set in 10 inches: At 30,000 lbs. per sq. in. | At 40,000 lbs. per sq. in. | At 50,000 lbs. per sq. in. | Ultimate. | Appearance of Fracture: Silky. | Granular. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sq. ins. | Inches. | Sq. ins. | Lbs. Tons. | Lbs. Tons. | Per cent. | Per cent. | Lbs. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. |
| 892 | 2 | turned 1·597 | 2·000 | 32,400 | 55,690 | 58·1 | 58·3 | 133,709 | 0·00 | 3·21 | 8·92 | 27·4 | 80 | 20 |
| 890 | do. | do. | do. | 30,700 | 55,045 | 55·7 | 56·7 | 127,124 | 0·00 | 3·68 | 9·64 | 27·9 | 95 | 5 |
| 888 | do. | do. | do. | 28,300 | 50,865 | 55·6 | 59·9 | 127,003 | 0·82 | 5·59 | 18·9 | 28·8 | 95 | 5 |
| 894 | do. | do. | do. | 28,100 | 49,810 | 56·4 | 68·2 | 156,635 | 0·96 | 6·20 | ... | 35·3 | 100 | 0 |
| | | | Mean | 29,875=13·3 | 52,852=23·6 | 56·4 | 60·8 | 136,118 | 0·89 | 4·67 | 12·49 | 29·8 | 93 | 7 |
| 898 | 2×2¼ | shaped ·75×·50 | ·375 | 41,500 | 57,590 | 72·0 | 66·6 | 172,768 | 0·00 | 0·00 | 7·81 | 24·8 | Silky | ... |
| 897 | do. | ·75×·50 | ·375 | 35,700 | 56,910 | 62·7 | 70·6 | 194,009 | 0·00 | 1·87 | 8·19 | 26·4 | do. | ... |
| 896 | do. | ·75×·48 | ·360 | 31,800 | 51,520 | 61·7 | 75·0 | 206,077 | 0·00 | 5·32 | 14·3 | 27·3 | do. | ... |
| | | | Mean | 36,333=16·1 | 55,340=24·6 | 65·5 | 70·7 | 190,951 | 0·00 | 3·59 | 10·10 | 26·2 | | |

David Kirkaldy & Son.

99 Southwark Street, London, S.E.,
28th May 1889.

The following are analyses of basic Robert steel made at the Blaenavon works:—

| | 1. | 2. | 3. | 4. |
|---|---|---|---|---|
| Carbon | ·112 | ·122 | ·102 | ·084 |
| Silicon | ·027 | ·022 | ·035 | ·100 |
| Sulphur | ·136 | ·048 | ·032 | trace |
| Phosphorus | ·080 | ·052 | ·049 | ·076 |
| Manganese | ·258 | ·411 | ·307 | trace |

Silicon in No. 4 has been repeated with result Si = ·093 per cent.

The following tables show (pp. 279–280) the total amounts of material used, and the resulting productions of the *acid* and *basic* converters at the Stenay works for the months of May and June 1889. The figures have been converted into English lbs.

## Results of Experiments with Steel Castings made by the "Robert" Process—Acid Steel (Stenay).

*Average Chemical Analysis of 24 Samples of various Steel Castings.*

| Silicon. | Manganese. | Carbon. |
|---|---|---|
| 0·144 | 1·077 | 0·250 |

*Average Tensile Test of the above 24 Samples.*

| Tensile Strain per Square Inch. | Elongation. |
|---|---|
| 31·3 tons. | 16·3 per cent. |

It is claimed by the inventor that, by the acid process, steel of any desired quality can be produced, and especially for making castings of the highest quality of soundness and finish; and that by the basic process a peculiarly soft, ductile metal is produced, equal in all respects to irons of the highest class manufactured in South Yorkshire and Staffordshire.

## ACID CONVERTER.

Loss . . . . 12·6 per cent.
To the 1000 { Coke . . 310
To the 1000 { Iron . . 1142

*May* 1889.

| Consumption in Eleven Days' Work = 124 Blows. | | | | | | | | | | | | | | Production. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coke. | Lime-stone. | Rids. I. | Rids. III. | Solvey I. | Solvey II. | Solvey III. | Ber-guette. | Old moulds. | Spiegel. | Ferro-Mang. | Ferro-Silicon. | Scrap. | Total. | Ingots. | Castings. | Scrap. | Total. |
| Lbs. 316,046 | Lbs. 8,184 | Lbs. 11,330 | Lbs. 48,620 | Lbs. 770 | Lbs. 29,238 | Lbs. 29,150 | Lbs. 82,720 | Lbs. 35,992 | Lbs. 2,398 | Lbs. 4,164 | Lbs. 6,769 | Lbs. 13,398 | Lbs. 264,550 | Lbs. 12,452 | Lbs. 214,368 | Lbs. 4,169 | Lbs. 230,989 |

## ACID CONVERTER.

Loss . . . . 12·8 per cent.
To the 1000 { Coke . . 292
To the 1000 { Iron . . 1146

*June* 1889.

| Consumption in Eleven Days' Work = 110 Blows. | | | | | | | | | | | | | | Production. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coke. | Lime-stone. | Rids. I. | Rids. III. | Solvey I. | Solvey II. | Solvey III. | Ber-guette. | Old moulds. | Spiegel. | Ferro-Mang. | Ferro-Silicon. | Scrap. | Total. | Ingots. | Castings. | Scrap. | Total. |
| Lbs. 67,443 | Lbs. 7,260 | Lbs. 70,070 | Lbs. 87,736 | Lbs. 14,520 | Lbs. 16,940 | Lbs. 11,220 | Lbs. 2,200 | Lbs. 2,200 | Lbs. 5,852 | Lbs. 3,555 | Lbs. 6,063 | Lbs. 11,770 | Lbs. 232,126 | Lbs. 3,190 | Lbs. 194,381 | Lbs. 4,917 | Lbs. 202,488 |

## BASIC CONVERTER.

Loss . . . . . 16 per cent.
To the 1000 { Coke . . 217
To the 1000 { Iron . . 1193

*May* 1889.

| Consumption in Fourteen Days' Work = 229 Blows. | | | | | | | | | | Production. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coke. | Lime-stone. | Lime. | Grey Iron. | White Iron. | Spiegel. | Scrap. | Esch. | Ferro-Mang. | Total. | Ingots. | Castings. | Scrap. | Total. |
| Lbs. 106,189 | Lbs. 14,982 | Lbs. 66,528 | Lbs. 427,350 | Lbs. 2,640 | Lbs. 1,045 | Lbs. 6,776 | Lbs. 46,970 | Lbs. 6,230 | Lbs. 491,011 | Lbs. 411,917 | Lbs. ... | Lbs. 740 | Lbs. 412,731 |

## BASIC CONVERTER.

Loss . . . . . 16·5 per cent.
To the 1000 { Coke . . 234
To the 1000 { Iron . . 1200

*June* 1889.

| Consumption in Thirteen Days' Work = 200 Blows. | | | | | | | | | | Production. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Coke. | Lime-stone. | Lime. | Grey Iron. | White Iron. | White Iron. | Scrap. | Esch. | Ferro-Mang. | Total. | Ingots. | Castings. | Scrap. | Total. |
| Lbs. 101,965 | Lbs. 12,134 | Lbs. 59,642 | Lbs. 296,010 | Lbs. 96,030 | Lbs. 7,920 | Lbs. 7,282 | Lbs. 31,680 | Lbs. 5,042 | Lbs. 448,964 | Lbs. 366,102 | Lbs. ... | Lbs. 5,016 | Lbs. 371,118 |

Considering the above results, and others which have actually been produced with this converter, one must admit that the subject deserves the most careful consideration before passing judgment upon its merits or demerits.

Blowing air on or near the surface of the metal bath in a converter is by no means a new thing. Sir Henry Bessemer informs me that he did this years ago in some of his first experiments. He remarked that in all cases when he blew on or near the surface, he obtained an abnormal amount of slag, and a dense brown smoke, caused by the large amount of iron burned. In every case he obtained better results the lower the tuyeres were placed. This occurred in all the various forms and shapes of converters that he tried.

As I believe that the Bessemer patents cover almost every conceivable way in which the blast could be introduced into the converter, it is difficult to see upon what foundation any claim of novelty in the Robert converter can be based, except as a patent of combination, which, however, I am informed, constitutes the claim of the inventor; while, if we admit that the rotation and decarburization of the bath, as described, can be effected, it is difficult to believe that a pressure of 4 lbs. of blast would be sufficient to produce an inclination of the surface of the bath as shown in fig. 5. That it will heap the slag up, and keep the surface of the metal exposed to the action of the air is obvious. In a liquid so dense and heavy as molten iron, it is difficult to believe that a complete and uniform circulation of the bath, as shown in fig. 14, could be effected with only 4 lbs. of blast, no matter in what manner the tuyeres are placed.

It seems self-evident that to produce a uniform decarburization, the metal bath must circulate or rotate before the blast in a regular and constant manner. Whether the Robert converter does this or not I am unable to say, but one thing is certain—I have seen it produce most excellent material. At what loss of iron, however, I was unable to obtain any satisfactory information. The promoters of the "*process*" claim that under normal conditions the waste from the cupola to the ladle is only about 12 per cent., and from 13 to 18 per cent. when a basic lining is used.

When I mentioned to Sir Henry Bessemer that excellent material had been produced in this converter, he replied that if you blow the proper amount of air, in any manner you please, through good pig iron, you will get a good steel. Whether such is a fact or not, we should not condemn the Robert converter *in toto* until it has failed to produce, under the same conditions, a *better* result when tried side by side with an ordinary Bessemer converter, or else failed to produce an equal result with a greater economy. May it not be possible that M. Robert has produced with somewhat similar means what Sir Henry Bessemer failed to do years ago?

The criticism that in the Robert converter, as in all small Bessemer converters, the blows are too cold, does not seem to be substantiated. At the Paris works, I timed the interval from the end of the blow until all the metal had been cast by means of small ladles to be from twenty-five to thirty minutes. As far as I could observe, the metal at the last ladleful was nearly as fluid as at the first.

I greatly regret that I have not had the time nor the opportunities to give this subject a more careful study, but it is to be hoped that, as many of the members will see the converters themselves, points which have been omitted, or but barely mentioned, in this paper will be brought out in the discussion.

## *DISCUSSION.*

Mr. Smith-Casson said he wished to ask Mr. Robert two questions—first, Why did he use 1 or 2 ton converters instead of 20 or 25 ton converters, where one would suppose that the cost of the erection, repairs, labour, and waste would be greatly diminished? Secondly, Did not the system of side blowing have the effect of destroying the sides of the converter? He was under the impression that this would have the effect of producing a disturbing influence on the sides of the converter, especially on the side opposite to the entry of the blast.

The President said that Mr. Robert was not present to answer the questions put by Mr. Smith-Casson. He proposed that the best thanks of the members be given to Mr. Garrison for his paper.

The motion was adopted.

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### Votes of Thanks.

The President then proposed the following resolutions:—

"That the best thanks of the Iron and Steel Institute, in public meeting assembled, be and are hereby tendered—

"To the President, Council, and Secretary of the *Société des Ingénieurs Civils*, for the cordial reception accorded to the Institute on the occasion of its meeting in Paris, and for the very successful arrangements which they have made for the present meeting.

"To the President, Council, and Secretary of the *Société d'Encouragement pour l'Industrie Nationale*, for the free use of their rooms, and for other facilities afforded by them, during the meeting of the Institute in Paris.

"To the owners and managers of the works to be visited at Creusot, the Loire, Longwy, the Nord, and the Pas-de-Calais, for throwing open their works for the inspection of members, and for the hospitality they have offered, on the occasion of the meeting in Paris.

"To the London, Chatham, and Dover Railway Company, the London, Brighton, and South Coast Railway Company, the South-Eastern Railway Company, the Chemin de fer de l'Ouest, and the Chemin de fer du Nord, for the exceptional facilities which they have afforded to the members of the Iron and Steel Institute on the occasion of their general meeting in Paris.

"To Mr. Henry Chapman, for the complete, satisfactory, and successful arrangements which, as Honorary Local Secretary, he has made, in connection with the *Société dès Ingénieurs Civils*, for the present meeting."

The resolutions were adopted by acclamation.

Mr. ADAMSON said that they would be neglecting an important duty if they did not, before closing, give their best thanks to their worthy President for the manner in which he had presided over the meeting, and the great work that he had performed so efficiently, even when he had been absent from the meetings, in perfecting the organisation, which had resulted in so pleasant a gathering. He begged to propose "that the best thanks of the Iron and Steel Institute be, and are hereby, tendered to the President, for the judicious and courteous manner in which he has presided over the Paris meeting." It was unnecessary that he should add anything to enforce the President's suitability for the position to which he had been appointed by the members of the Institute. Personally, he rejoiced to think that they had so good a President, and he hoped that he would have equally good health, and would feel equally at home, when they met him, as he hoped most of them would do, next year in America.

Mr. S. R. PLATT had great pleasure in seconding Mr. Adamson's proposal, which required no further words from him. They all knew the President's great ability, and it must certainly be a

gratification to him to see so many members attending the Paris meeting.

The motion was carried by acclamation.

The PRESIDENT said he was much obliged to the members for having passed the vote of thanks so cordially. He was proud to think that the meetings they had held had been, perhaps, the most successful meetings of the Institute. As their numbers increased, so their influence would extend, and the usefulness of their proceedings would be more widely felt. If he had been able so far to serve the members satisfactorily, he hoped that he might be permitted to continue to do so with equal approbation until the end of his term.

# APPENDIX.

## *PRESIDENT'S DINNER.*

On the evening of Monday, the 23rd September, the President entertained the Council at dinner at the Restaurant Voisin, Rue St. Honoré. There were present—Mr. Daniel Adamson, Sir Frederick Abel, C.B., Sir Lowthian Bell, Bart., M.P., Mr. William Evans, Mr. P. C. Gilchrist, Mr. T. E. Horton, Mr. S. R. Platt, Mr. E. W. Richards, Mr. James Riley, Mr. J. T. Smith, Mr. Benjamin Walker, and Mr. William Whitwell, Members of Council; Mr. G. Eiffel, Sir William Harcourt, M.P., Colonel J. T. North, Mr. F. Siemens, Mr. Kitson, jun., Mr. G. Findlay, Mr. H. Chapman, Mr. Vaslin, Mr. Jeans (General Secretary), &c. Several toasts were proposed and responded to, and a very agreeable evening was spent, the dinner being served in the best style of Voisin's famous establishment.

## *ANNUAL DINNER OF THE INSTITUTE.*

The Annual Dinner of the Institute was held on the evening of Wednesday, the 25th September, at the Hôtel Continental. The chair was occupied by Sir James Kitson, Bart., President of the Institute, who was supported by Sir Lowthian Bell, Bart., F.R.S., Past-President; Mr. Daniel Adamson, Past-President; M. Gustav Eiffel, President of the *Société des Ingénieurs Civils;* Sir Frederick Abel, C.B., Mr. E. Windsor Richards, Mr. James Riley, Mr. Gilchrist, Mr. T. E. Horton, Mr. S. R. Platt, and Mr. William Whitwell, members of Council, and a number of gentlemen connected with the iron and engineering trades of France. Altogether, about 250 sat down.

After dinner, the President proposed the toasts of "the Queen," and of "the President of the French Republic." He afterwards proposed the toast of the *Société des Ingénieurs Civils*, coupled with the name of M. Eiffel, President of the Society, and in doing so paid a

compliment to M. Eiffel's genius and taste as an engineer, and expressed the thanks of the members for the extremely hospitable reception that had been given to the Institute in Paris.

M. Eiffel, in acknowledging the toast, said it became him, as President of the Institute of Civil Engineers of France, to testify how much the kind words of the President were appreciated by that body. The Iron and Steel Institute had no need to offer thanks for the reception that it had met with in France. It was a privilege and an honour to receive there so distinguished a body. The French engineers did not forget the part which had been taken by English engineers and metallurgists in advancing the interests of their great industry, which had been elevated by them to its present position. The education of the rest of the world in metallurgic arts had been founded upon the example and experience of Great Britain. Frenchmen thanked England for what she had done, and he was that evening the mouthpiece of all French engineers in rendering that homage. He hoped that the excursions they were about to make to the leading ironworks of France would result in personal relations that would be for the benefit of both countries. M. Eiffel concluded by proposing the toast of "The Iron and Steel Institute," coupled with the name of the President, Sir James Kitson.

The toast was drunk with enthusiasm, and the President made a suitable response.

The other toasts were "Our Hosts at the Creusot, the Loire, Longwy, Luxembourg, the Nord, and the Pas-de-Calais," proposed by Sir Lowthian Bell, Bart., and responded to by M. Jambille; and "Our Guests," proposed by Sir Frederick Abel, and replied to by Mr. C. B. Richards.

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## CONVERSAZIONE.

On the evening of Tuesday, the 24th September, the members were entertained at a Conversazione at the Hall of the *Société des Ingénieurs Civils.* A large number accepted the invitation, and a very agreeable entertainment, including excellent music and experiments with scientific apparatus, was provided.

# VISITS AND EXCURSIONS.

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## Inspection of the Eiffel Tower.

On the morning of Thursday, the 26th of September, the members of the Institute assembled at the Eiffel Tower (south pier), where they were met by M. Eiffel and by a number of members of the *Société des Ingénieurs Civils.* The party were carried to the top of the third platform (905 feet in height), where they spent a considerable time in examining the arrangements of the tower, and in admiring the far-reaching prospect that lay around in all directions. Fortunately the weather on the occasion was all that could be desired.

At twelve o'clock the members were entertained at luncheon at the Restaurant Brebant, on the first platform, by the *Société des Ingénieurs Civils.* M. Eiffel presided. More than 300 sat down, and the spacious restaurant was filled to overflowing.

After lunch, Sir James Kitson, President of the Institute, proposed the health of M. Eiffel in appropriate terms, and congratulated him upon his success in the construction of so graceful a structure as the tower that bears his name.

M. Eiffel responded as follows :—

Messieurs,—Je ne veux pas renouveler les toasts qui ont été portés hier, avec tant de dignité et de courtoisie, par votre Président, Sir James Kitson. Je tiens seulement à vous dire que je suis heureux d'avoir, au nom de la Société des Ingénieurs Civils à vous recevoir ici et d'avoir pu vous faire visiter en détail, cette Tour qui est l'une des plus grandes constructions métalliques qui aient été faites. Nous savons en effet que vous excellez dans l'art de ces constructions oú vous avez débuté si glorieusement par le Pont Britannia avec Stephenson et où vous poursuivez votre brillante carrière avec le Pont du Forth auquel les noms de MM. Fowler et Baker resteront à jamais attachés.

Bien d'autres constructions, notamment la galerie des machines dont

les projets ont été établis par l'un des notres, Mr. Contamin, ont dû attirer votre attention et vous montrer les progrès qu'a faits la France, dans cet art où vous nous avez précédés, mais où vous rencontrez des émules dignes de vous. Vous aurez certainement regretté que les grandes nations n'aient pas participé à notre Exposition d'une manière plus complète, mais en ce qui concerne l'Angleterre, vous aurez eu une fois de plus, un remarquable exemple de ce que peut l'industrie privée qui est l'une des traditions de votre grand pays. Sous l'impulsion énergique d'un homme dont j'áime à rappeler le nom, le précédent Lord Maire de Londres, Sir Polydore de Keyser, une exposition Britannique s'est constituée et vous savez tous avec quel succés. Il a été aidé dans cette tâche à laquelle il s'est dévoué, par l'un des membres les plus sympathiques de votre Société, Mr. Henry Chapman.

Son A. R. Monseigneur le Prince de Galles et sa famille ont été parmi les premiers visiteurs de notre Exposition, et Mr. Gladstone parmi les plus récents; j'ai eu l'honneur de les guider moi-même jusqu'à la partie la plus élevée de cette Tour et de recueillir les témoignages de leur satisfaction pour les travaux des Ingénieurs Français.

J'espère, Messieurs, qu'il en sera de même pour vous et que vous remporterez dans votre pays une bonne impression de votre visite qui cimentera les liens d'estime et de sympathie réciproques qui doivent unir nos deux pays, que nous confondons dans un même toast, en buvant à leur commune prospérité.

*Vive l'Angleterre! Vive la France!*

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## Le Creusot.

A party of upwards of sixty members left Paris on the evening of Thursday, the 26th September, for the purpose of inspecting the great works of Creusot. The party reached the station of that name after a very comfortable journey—sleeping-cars having been provided by the P., L., and M. Railway Company—about eight o'clock on the morning of the 27th. They were met by the heads of the various departments, including M. Barba, the general manager, and conducted to hotels in the town, where breakfast was provided for them. Without any loss of time, they were afterwards conducted to the works, where M. Henri Schneider and his son met them at the entrance to the rolling-mills, and showed them over the whole of the vast establishment, an undertaking which occupied the whole of the day, with an interval for luncheon, until nearly five o'clock in the afternoon. The principal

items on the printed programme which had been prepared for the guidance of the party were as under :—

8.30 A.M.—Inspection of the rolling-mills.
10 „ Visit to the forge, with the steam-hammer of 100 tons and the press of 6000 tons.
10.45 „ Visit to the artillery shops.
11.15 „ Visit to the polygon, where a 24-cm. gun was to be fired.
11.45 „ Proceed to the offices of the firm.
12 noon.—*Déjeûner.*
2.15 P.M.—Resume inspection of the works.
2.30 „ Visit the engineering shops.
3.45 „ Visit the steelworks, passing *en route* the blast-furnaces.
4.30 „ Proceed to the chief offices for refreshments.
5.00 „ Leave by train for Dijon.

The above programme was adhered to as closely as possible, and M. Schneider and his chief managers and engineers, who remained with the party throughout the day, were indefatigable in answering all questions, and affording all information likely to be useful or interesting to their guests.

The visitors observed in the rolling-mills all the operations that are usual to such an establishment, except, perhaps, the manufacture of rails, which are not now produced at Creusot to any extent. The chief manufactures were bars, channels, deck plates for protected cruisers, and wire rods. There were many different trains of rolls in operation, and alongside of these were ordinary and mechanical puddling furnaces. Three high rolls were employed in the rolling of H iron. The bars used for this purpose were delivered on to a floor which was crossed by several slides, in which pitched chains carrying lugs were worked. These chains were set in motion when a bar was delivered, and the lugs projecting above the floor carried the bar to one side of the space provided for it. For the heavier sections of bars, the mills employed had rising and falling tables at each side, which rose or fell as required to deliver the bloom to the rolls. These movable tables are worked by steam cylinders, and serve to reduce considerably the labour of the men. For the rolling of deck plates a large and powerful reversing mill is employed, capable of rolling ingots up to 11 or 12 tons. An 11-ton ingot was passed through this mill in the presence of the visitors, and reduced to a plate, intended for the deck of a Chilian cruiser, which measured 14 metres in length, by 1·56 metre in width, and 50 millimetres thick.

In the forging department, which the party next visited, the great centre of attraction was the 100-ton hammer, one of the first erected in Europe, and the hydraulic press of 6000 tons capacity. The hammer bore the date 1876, and at the time of the visit a 30-ton ingot was being reduced to a crank shaft by the labour of some eighteen men. The large hammer is also employed in the manufacture of armour-plates. The 6000-ton press was seen at work in bending plates to the required form for covering turrets, barbettes, and other similar requirements; and this duty it appeared to do very thoroughly. The firm propose to introduce a hydraulic press for the forging of armour-plates in the place of the 100-ton hammer. Smaller steam-hammers of 8, 15, 20, and 40 tons, respectively, were employed in the same building, in the forging of tyres, axles, &c., which the visitors examined with interest.

From the forge, the party was conducted by a special train to another department of the works devoted to artillery purposes. This shop is exceedingly light and airy, is of large dimensions, and is spanned by a 60-ton travelling crane. Guns in various stages of manufacture were seen throughout the shop, together with their fittings and carriages, all in cast steel. The shop contained the usual assortment of boring, punching, slotting, shaping, and other machinery, a good deal of it of English manufacture.

It was a natural and easy transition, again by special train, from the artillery workshops to the polygon where the guns are tested. A gun of 24 centimetres, constructed for the Chinese Government, was here fired in the presence of the party, with a projectile of 348 lbs. and a charge of 191 lbs. of powder. The shot travelled at a velocity of 2200 feet per second, and, after hitting the target, disappeared in the embankment of sand at the other end of the polygon.

*Presentation of the Bessemer Gold Medal to M. Schneider.*

At twelve o'clock the party sat down to a very excellent luncheon, in the principal hall of the town, where they were joined by the chief members of the administrative staff. During luncheon, the Creusot band, composed entirely of the *employés* of the firm, played a number of airs so well that, before leaving the table, Sir Lowthian Bell, on behalf of the party, sent for and personally thanked the conductor. The chair was occupied by M. Henri Schneider, who, after luncheon, proposed the health of "the Queen," which was received with enthusiasm. Next came the presentation of the Bessemer Gold

Medal, which had been awarded to M. Schneider by the Council of the Institute, and was to have been presented to that gentleman at Paris, had he not, by public duties, been prevented from attending.

Sir Lowthian Bell, Bart., F.R.S., Past-President of the Institute, on behalf, and at the special request, of the Council, made the presentation in the absence of the President, who had arranged to proceed with the party visiting the works in the district of the Loire. Sir Lowthian, in the course of his remarks, referred to the long connection that had existed between M. Schneider and himself, and to the enterprise and ability with which the great works at Creusot had always been conducted. Among other special qualities required for conducting such a gigantic establishment as that which constituted one of the objects of their visit, was the ability to select a suitable staff for carrying out the instructions of the commander-in-chief. Sir Lowthian referred to his long acquaintance with M. Barba and other officers entrusted with the direction of the Company's affairs, and was able from personal observation to speak with great confidence of their high capacity and intelligence. Those qualities had enabled M. Schneider and his distinguished father to establish there, almost in the centre of France, and far removed from the sea, the most important works of their kind in that great and important country. M. Schneider had shown his appreciation of the value of new processes and improvements, such as it was the special business and aim of the Iron and Steel Institute to promote, in many ways. He had, at a comparatively early date, taken up the manufacture of Bessemer steel, and, more recently, he had carried out the basic processes in a satisfactory manner. The connection of Creusot with the early introduction of the steam-hammer was very well known; and so also with other mechanical and metallurgical advances. Sir Lowthian had no doubt that the members of the Institute would derive both pleasure and profit from their visit to Le Creusot on that occasion, and he thanked M. Schneider on their behalf for the considerate and liberal hospitality with which they had been received. Sir Lowthian concluded by proposing the health of M. Schneider and his family.

M. Schneider, on receiving the medal from the hands of Sir Lowthian, made an appropriate reply. He expressed, first of all, his satisfaction at seeing so many members of the Institute at Le Creusot, although he would have been better pleased if many more had come. He deeply felt the honour which had been conferred upon him by the Council of the Institute in awarding to him the blue riband of the

iron and steel trades—an honour which had been awarded to many distinguished metallurgists in the past. Much of the prosperity of his works at Le Creusot he considered to be due to the sympathy that existed between his *personnel* and himself. He was sorry that he had not been able to attend the Paris meeting of the Institute, but he thanked the Council and members for their favourable reception of his paper on the Channel Bridge, which he had been anxious to submit, in the first place, to English engineers and metallurgists. He asked the members to take the project under their protection, as it was only by the union of the two countries that it could ever be successfully carried out. In conclusion, M. Schneider drank to the continued success of the Iron and Steel Institute.

M. Périssé, Vice-President of the *Société des Ingénieurs Civils*, proposed the health of the *personnel* of Le Creusot, to which M. Barba responded, referring more especially to the friendly reception that was usually accorded in England to French engineers.

Each member of the party, on leaving the luncheon-room, received a souvenir of his visit in the form of a *menu* stand, the base of which was polished steel, and the upper part the model of an armour-plate.

Shortly after two o'clock the party resumed the inspection of the works, descending by the *grand escalier* to the engineering shops, where they witnessed locomotive engines in all stages of construction, and afterwards proceeding to the foundries, where they saw, among other work, the moulding of the screw propeller of the *Alger*, and of the *voussoir* of the turret of a Belgian ironclad.

In the "*tournerie de marine*," or marine engine shops, the party found two sets of engines in course of construction—the first, engines of 12,000 h.-p. for the s.s. *Magenta;* and the second, engines of 8000 h.-p. for the *Alger*. There were also being turned out *Corliss* engines of 500 h.-p. for the small arms manufacture of Chatellerault. In the adjoining "*chaudronnerie de marine*" they found a number of boilers in various stages of construction, including one with three fires for the *Isly*, and another set for the *Magenta*. The locomotive boiler-shop adjoining was also examined with interest, especially as a good deal of work was in hand.

The last departments of the works visited were those devoted to the manufacture of Bessemer and open-hearth steel, both of which are carried on here. The plant employed does not seem to call for any special remark, unless it be that rotatory furnaces are employed for the pro-

duction of a superior quality of iron for the Siemens furnaces. A very considerable use appears to be made of the steel-foundry, where a number of large castings, intended for ships of war, were seen in process of being cast. The Siemens furnaces were also witnessed in the operation of casting an ingot of 50 tons weight.

After partaking of light refreshments at the offices of the firm, the party proceeded to the railway station, where M. Schneider and his managers wished them cordial adieux. As the train moved off a parting cheer was given for Le Creusot and its owners. A considerable stay was necessary at Dijon on the return journey, which was utilised in partaking of a sumptuous dinner, provided by M. Schneider, and presided over by his only son. After this dinner, several toasts were proposed and responded to by Mr. W. Whitwell, Mr. James Riley, and others.

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## The Loire.

At 8.5 P.M. on the evening of Thursday, the 26th September, a party of about forty members of the Institute left the Gare de Lyon (Bourbonnais line) for the Loire, the Paris, Lyons, and Mediterranean Railway having provided very excellent facilities for the occasion. Sir James Kitson, President of the Institute, and M. Gustav Eiffel, were among the party. On arriving at St. Etienne, at 8 A.M. next morning, the party were received by M. Reymond, Senateur de la Loire; M. Cholat, President of the Association of Ironmasters of the Loire; M. Chalmeton, Director of the Steelworks of Firminy; and M. Lucien Thiollier, Secretary of the Chamber of Commerce of St. Etienne.

Having been conveyed to their hotels, and allowed an interval for rest and refreshments, the members were conveyed by special omnibuses to the works of the *Société des Aciéries de St. Etienne*, which are about 2½ miles from the town. These important works are chiefly employed in the manufacture of cast steel armour-plates and heavy forgings. The pig iron is for the most part bought under contract from other works.

Among the operations witnessed at these works was the forging of an ingot intended for a 9·6-inch naval gun by a 50-ton hammer. A Pernot open-hearth furnace, of 15 tons capacity, was seen in operation, and excited some attention, this being almost the only furnace of its kind in the district. A small open-hearth furnace, of 5 tons capacity, was worked with a basic lining, made of carbonate of lime only. The

bed, which requires forty-eight hours' firing, was made of crushed limestone, mixed with a little iron ore.

After partaking of luncheon, provided by the Associated Steelworks of St. Etienne, Firminy, and Unieux, the party, in the afternoon, examined the works of Firminy and Unieux. The plant at Firminy is chiefly open-hearth, there being eight furnaces of this type, all of considerable size. The works have also three Siemens furnaces for the crucible steel process, and they possess a large steel-casting foundry, two large rolling-mills, and workshops for the production of springs, tools, axles, &c. Chemical and physical laboratories are attached. The Firminy Works were among the first to engage in the chrome-steel industry in France. They employ some 2000 hands.

At the Works of Unieux, belonging to the well-known firm of Holtzer & Company, the principal products are chrome steel, manganese steel, copper steel, wolfram steel, and other specialities. The properties of some of these descriptions of steel, as manufactured at Unieux, were described by M. Brustlein in a paper read before the Institute in 1886 (*Journal*, No. ii., p. 770). The Unieux Works make a speciality of the manufacture of chrome-steel shells and plates, specimens of which were seen in the Exhibition. The basis of the steel productions of Unieux is the charcoal pig made at Ria, in the Eastern Pyrenees, from spathic ores. The works have twelve converting furnaces for blister steel, the melting furnaces being of the Siemens type. Tool steel, containing tungsten and chromium, are the chief products of the Unieux Works. Puddled steel and iron are both produced at Unieux, the larger part being converted into cast steel as a final product.

In the evening the members were entertained at dinner by the Chamber of Commerce of St. Etienne at the Palais des Arts. The Préfet of the Loire occupied the chair, supported by the President of the Institute (Sir James Kitson), M. Gustav Eiffel, M. de Montgolfier, President of the Chamber and director of the works of St. Chamond, M. Louis Holtzer of Unieux, M. Cholat of St. Etienne, &c. The band of the 38th Regiment of infantry played during the banquet a number of well-known airs, including "Rule Britannia," "God save the Queen," and the "Marseillaise."

After dinner, the Chairman rose and thanked the Chamber of Commerce for having given him the opportunity of presiding on so interesting an occasion. He also thanked the members of the Institute who had visited the Loire on that occasion, and proposed a toast to the

engineers of all countries, and especially those of the Iron and Steel Institute.

The PRESIDENT of the INSTITUTE acknowledged the toast, and proposed the health of M. Carnot, in his double capacity of chief of the State and engineer.

M. DE MONTGOLFIER, in proposing the health of Her Majesty the Queen, took occasion to deliver an interesting address on the part which had been taken by the metallurgists and engineers of the Loire in the development of industry and transport. He spoke as follows:—

MESSIEURS,—Après le discours éloquent, charmant et plein d'humour que vous venez d'entendre, il m'est difficile de prendre la parole. Votre honorable Président, Sir James Kitson, rend la tâche bien ingrate à ceux qui lui succèdent. Aussi de toutes les questions si intéressantes auxquelles il a touché avec tant de verve et d'entrain, je n'en retiendrai qu'une, le plaisir que nous font sa visite et la vôtre, Messieurs. Je vous remercie en mon nom, au nom de la Chambre de Commerce, au nom du Comité des Forges de la Loire et des notabilités du département qui ont répondu à notre appel, d'avoir bien voulu, après les fatigues de l'Exposition, entreprendre un long voyage pour venir jusqu'à nous.

A vrai dire, Messieurs, votre visite nous était un peu due. Car vous êtes ici dans la région qui a donné naissance, en France, à la grande industrie des chemins de fer et à la grande industrie de la métallurgie; et dans ces deux branches importantes de l'activité humaine, vous avez été nos précurseurs et nos maîtres. Il était donc tout naturel que vous vinssiez constater si nous avions su profiter de vos premières leçons.

J'ai dit que la grande industrie des chemins de fer avait en France débuté dans ce pays. Nous devions avoir ce soir parmi nous (et pour ma part je regrette vivement son absence) le fils de l'homme éminent, de l'ingénieur distingué, qui a attaché son nom à cette création. J'ai nommé Marc Seguin, le neveu, le disciple, j'ajouterai le continuateur du génie de mon grand-oncle, Joseph de Montgolfier.

Après le succès obtenu en Angleterre par l'illustre Stephenson dans l'exploitation par locomotives de sa ligne de Darlington-Stockton, succès confirmé plus tard en 1829 par le mémorable concours de Manchester, Marc Seguin comprit que le chemin de fer allait transformer et révolutionner le vieux monde, et sans se laisser décourager par la tentative peu fructueuse faite en 1823, par M. Beaunier, ingénieur en chef des mines, homme d'initiative et de science, dans l'établissement d'un chemin de fer à traction de chevaux entre Saint-Etienne et Andrézieux-sur-Loire, il entreprit en 1826, avec une audace qui nous étonne encore

aujourd'hui, et, à l'aide de ressources bien modestes, la construction de la première ligne pratique à voie normale exécutée en France, celle de Saint-Etienne à Lyon qu'il prolongea ensuite de Saint-Etienne à Roanne.

Vous retracer les difficultés de tous ordres qui furent surmontées m'entraînerait trop loin. Il me suffira de vous rappeler que la ligne comportait des travaux exceptionnels pour l'époque. Il y avait un grand pont sur la Saône à construire, de grands tunnels à percer. Marc Seguin ne recula devant aucun obstacle, ni aucun sacrifice, et son tracé, ainsi que pourra l'attester M. Mauris, l'ingénieur si aimable de la compagnie P.-L-M. que nous avons le plaisir d'avoir ce soir parmi nous, est resté, après le remaniement des ouvrages et de la voie, tel qu'il était sorti de ses mains.

Vous dirai-je qu'en 1826 on ne faisait de rails en fer forgé ou laminé nulle part en France? Marc Seguin passa outre et établit sa première voie en fonte.

Restait la locomotive. Le mécanisme, le changement de marche étaient trouvés. Mais elle manquait de souffle et de poumons. Marc Seguin lui donna l'un et l'autre en inventant, en 1828, la chaudière tubulaire. Ce fut là un trait de génie qui complétait la solution du problème de la traction à vapeur. Stephenson et Marc Seguin l'avait résolu d'un seul jet et créé l'instrument de civilisation et de progrès le plus merveilleux de notre siècle.

Malgré tout, comme les rails étaient légers et qu'on ne pouvait pas charger de plus de 5 à 6 tonnes les essieux des locomotives, la traction par vapeur était impossible sur la rampe de 18 $^{m}/_{m}$ par mètre entre Rive-de-Gier et Saint-Etienne. C'est alors que Verpilleux (vous permettrez de rappeler un souvenir qui m'est cher), qui devait plus tard résoudre la question de la navigation du Rhône par ses bâteaux grapins, construisit sa locomotive avec vapeur au tender. En doublant l'adhérence, il doubla la force et remplaçat, comme il le disait lui-même dans son langage pittoresque, "les chevaux mangeant de l'avoine par ceux qui n'en mangeaient pas."

L'œuvre de Marc Seguin était dès lors définitive, assurée. La prospérité de la région prenait un essor inouï et le trafic considérable de la ligne de Saint-Etienne à Lyon dépassait bien vite toutes les prévisions et toutes les espérances. Il s'élève aujourd'hui à 4,000,000 de tonnes et les recettes brutes par kilomètre excèdent 350,000 francs.

Vous le voyez, Messieurs, votre initiative en chemin de fer a été promptement suivie par nous. En métallurgie, vous n'avez pas été seulement des précurseurs, vouz avez été nos maîtres.

Les premiers grands hauts-fourneaux au coke construits en France l'ont été à la Voulte-sur-Rhône et à Terrenoire. Ils ont fonctionné grâce aux machines soufflantes de Watt importées d'Angleterre à Marseille. Ces machines conduites, réparées, entretenues pendant longtemps au début par Verpilleux, existent encore aujourd'hui.

Les premiers fours à puddler ont été établis à Terrenoire et desservis par des ouvriers anglais dont les fils et petits-fils travaillent dans nos usines.

La fabrication des aciers (aciers au creusets, les seuls connus en 1820) a été introduite en Feance par M. Jackson, à Lorette, une des usines de notre Société.

Après l'admirable invention de Bessemer, la première cornue qui ait fonctionné pratiquement a été montée dans nos forges d'Assailly, que vous apercevrez demain en allant de Saint-Chamond à Rive-de-Gier. Elle a fourni, dès sa mise en marche, les rails d'acier de la rampe d'Etampes, qui n'ont pas été remplacés depuis.

Siemens est arrivé ensuite avec ses générateurs à gaz et son merveilleux récupérateur de chaleur. Le premier four Siemens-Martin établi en France a fonctionné dans l'aciérie de M. Verdié, à Firminy, que vous avez visitée ce matin.

Enfin demain, en traversant nos usines et celles de MM. Marrel, vous constaterez une large application des procédés si intéressants de M. Wilson pour la fabrication des plaques " compound."

Vous voyez, Messieurs, que nous avons abondamment puisé dans vos méthodes. Mais j'ajoute que nous avons cherché à les développer, à les améliorer de façon à rester toujours à la tête du progrès dans les fabrications difficiles que notre situation géographique et l'absence de tout minerai nous permettent seules de maintenir dans notre région, ainsi que nous le faisait remarquer tout à l'heure Sir J. Kitson.

C'est ainsi, Messieurs, que le marteau-pilon, inventé par Nasmyth et Bourdon, perfectionné par Verpilleux, a trouvé chez MM. Petin-Gaudet, les fondateurs de notre Compagnie et mes éminents prédécesseurs, sa première application.

C'est ainsi qa'à Saint-Chamond ces mêmes maîtres de forges ont fabriqué les premières plaques de blindages en Europe. Elles armaient les canonnières françaises à l'attaque de Bomarsund.

C'est ainsi que dans les mêmes usines furent laminés, pour la première fois, les bandages sans soudure, et c'est à Rive-de-Gier, avec les lingots d'Assailly, que furent forgés, bien avant que l'usine Krupp ne fût

connue, les tubes et canons en acier dont la Marine française peut s'honorer d'avoir fait en Europe les premières applications.

C'est enfin notre région qui peut revendiquer la fabrication en étampes des corps de roues de wagons et de machines, et depuis quelques années la fabrication des projectiles et des tôles en acier dur au tungstène et au chrome dont les usines de la Loire ont gardé le monopole.

Je termine, Messieurs, cette nomenclature un peu longue. Vous m'excuserez en pensant comme moi que dans une réunion comme celle-ci il était bon de rappeler à grands traits l'histoire industrielle de notre pays, et à côté des noms illustres des Watt, des Stephenson, de Bessemer, de Siemens, de Wilson, de placer les noms de Marc Seguin, Beaunier, Verpilleux, Petin, Gaudet, Jackson, Martin, Jacob Holtzer et tant d'autres qui ont si grandement honoré notre pays. Ces hommes ont eu l'audace, l'intuition et à des degrés divers une parcelle de ce je ne sais quoi qui vient de Dieu et qu'on appelle le génie. Dans tous les cas, vous reconnaitrez en eux les véritables bienfaiteurs du peuple.

A nous de les imiter en suivant le sillon lumineux qu'ils nous ont tracé. Travaillons, comme ils ont travaillé eux-mêmes, à la marche en avant de la science et au bien-être de l'humanité.

Tous les progrès, Messieurs, que je vous ai signalés ont été réalisés et accomplis pendant le règne long et fécond d'une Souveraine qui a daigné souvent visiter la France et manifester dans bien des cas sa sympathie pour notre pays. Je vous demande, Messieurs, la permission, en réponse au toast si aimable de Sir James Kitson au Président de la République, de porter à mon tour un toast à Sa Gracieuse Majesté la Reine d'Angleterre. Que Dieu lui accorde de longs jours pour le bonheur des peuples et la paix du monde !

The other toasts included the *Société des Ingénieurs Civils*, coupled with the health of M. Eiffel, who responded, and the fraternity of European countries, proposed by the Chairman.

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On the morning of Friday, the party proceeded to the important works of St. Chamond and of Rive-de-Gier. Sir James Kitson and M. Eiffel accompanied the party, which was swollen by the presence of a large number of the notabilities of St. Etienne and the district. At the station of Châteaucreux, a special train was placed at the disposal of the party by the Paris, Lyons, and Mediterranean Railway Company. Arrived at St. Chamond, the party were received by M. de Montgolfier,

who gave them a cordial welcome. The inspection of the works was commenced at the great forge, where a 100-ton hammer was seen forging an ingot of 25 tons weight, for a gun of 240 millimetres. This hammer has, however, repeatedly dealt with ingots of 50 tons, and even of 90 tons, for 34-centimetre guns, and with plates of 60 tons. In the *grand atelier*—a large hall of 110 metres in length by 70 metres in width, with two travelling cranes of 30 tons, similar to those seen at the *grand galerie des machines*, or machinery hall, at the Exhibition—a number of guns were being turned and finished. Alongside this fine shop there was another of 70 metres in length by 25 metres in width, served by a crane of 100 tons, where auxiliary work was done. After passing through the *ateliers de laminage*, or rolling-mills, the party were conveyed to the open-hearth steel plant, where two Siemens furnaces were used to produce an ingot of 20 tons weight.

The Works of St. Chamond, in the Loire, were founded in 1837 by MM. Petin and Gaudet, and were transferred to a new proprietary in 1854, when the steelworks and forges of Assailly, the forges of Lorette and of Persan, and the charcoal blast-furnaces of Chairères and Toga were acquired. The Company also own the Works of Givors (Rhône) and the collieries of Mieux and Fraisse in the Loire.

At the Works of Rive-de-Gier, the St. Chamond Company (describing themselves as the *Compagnie des Hauts-foruneaux Forges et Aciéries de la Marine et des Chemins de Fer*) manufacture large forgings for steamships, and have special works for the production of forged wheels.

Having left the Rive-de-Gier Works, the party proceeded to examine the well-known works of MM. Marrel Frères.

These works are of large extent, and are specially laid out for the production of steel in large masses. They have cast ingots up to 85 tons in weight, and have proved their ability to cast ingots up to 140 tons. A 100-ton hammer is now being erected at the works, which has an anvil-block 800 tons in weight and a cylinder of 2 metres diameter. The plant employed embraces four 35-ton furnaces, and the principal productions include tubes and hoops for heavy guns, compound armour-plates, structural bars, &c. While the party were going over the works, they witnessed the forging of a 55-ton ingot by the 50-ton hammer. At the collation which followed, M. Charles Marrel proposed the health of the two Presidents—of Sir James Kitson, President of the Institute, and of M. Eiffel, President of the *Société des Ingénieurs Civils.*

A short visit was afterwards paid to the works of MM. Deflassieux and of MM. Arbel Frères, where the forging of wheels, &c., of which the pieces are usually stamped hot, was witnessed.

On the return journey, the members of the Institute were entertained at dinner, at the station buffet at Lyons, by the *Société des Ingénieurs Civils,* in thanking whom, for their great hospitality, Sir James Kitson expressed a hope that they might soon arrange to pay a visit to England. M. Eiffel drank to the health of all the party, and wished them a successful termination of their journey.

The excursion into the Loire was, from first to last, marked by the greatest cordiality and kindness on the part of the several hosts. Not only so, but the people of St. Etienne, of Rive-de-Gier, and of other places visited, turned out in large numbers to receive their visitors, and showed the greatest possible attention to them. The visit passed off without a hitch, and is likely to be long remembered by those who were privileged to take part in it.

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## Excursion to Longwy and Luxembourg.

Those members of the Iron and Steel Institute who visited the iron-producing districts of Longwy and Luxembourg had a very enjoyable trip, and were most hospitably entertained by the *Maîtres de Forges du Groupe de Longwy,* and by the firm of Messrs. Metz & Co., and others.

The party left Paris on the evening of Thursday, the 26th September, and arrived at Longwy at six in the morning, where they were met by a large party of the *Comptoir du Longwy,* who accompanied them in their visits to the various works.

The first works visited were those of Messrs. Ratz & Co, at Saulnes, where the party was met by the Messrs. Ratz, by whom they were conducted over the blast-furnaces and works. The works comprise three blast-furnaces, with eleven Cowper stoves. The slag is used up for cement by a special process at accessory works close to thê furnaces, which consists in mixing the granulated slag with partially slaked lime. The blast-furnaces have a height of 18 metres, and a capacity of 294 cubic metres.

The next place visited was at Hussigny, where, conducted by M. Mahoux, one party visited the works and blast-furnaces of *La Société Lorraine Industrielle,* of which Mons. Mahaux is managing director;

whilst a second party, conducted by Mons. Caron, *Director des Minières de la Côte Rouge*, visited the quarries from which the ores of the *Minières de la Côte Rouge* are extracted.

This important ore deposit, which runs nearly horizontal, has a total depth of about 15 metres, and is worked entirely from open workings. There are five principal ore-beds, of which the following are the thicknesses and analyses :—

| | Calcaire Superior (2·25–2·50 m.). | Calcaire Inferior (2·00–2·25 m.). | Mine Rouge (4–5·50 m.). | Mine Grise (3·50–4 m.). | Mine Noire (2·50 m.). |
|---|---|---|---|---|---|
| Volatile matter . | 21·30 | 23·00 | 14·48 | 13·00 | 12·40 |
| Silica . . . | 12·35 | 10·67 | 13·70 | 14·90 | 10·40 |
| Alumina . . | 4·80 | 5·85 | 6·70 | 8·21 | 6·13 |
| Lime . . . | 14·57 | 19·89 | 7·70 | 2·51 | 3·09 |
| Magnesia . . | ... | 0·54 | ... | ... | 0·82 |
| Phosphorus . . | ... | ... | 1·52 | 1·58 | 1·77 |
| Metallic iron . | 31·95 | 27·40 | 40·50 | 40·70 | 45·90 |

The ore is quarried very cheaply, and it can be delivered at the best-situated blast-furnace works at two francs the ton. As these ores are not quite self-fluxing, some calcareous ore has to be imported from Luxembourg in order to provide the necessary lime.

At the works of *La Société Lorraine Industrielle* there are two blast-furnaces, each of 17 metres in height and 370 cubic metres capacity, with three Cowper stoves to each furnace. The production per furnace is from 90 to 100 tons of forge pig per day.

At 10.30 the party reached Villerupt, where, conducted by Mons. le Comte de Retz, one of the directors, the works of the *Compagnie Chatillon-Commentry* were visited. These works consist of two blast-furnaces, which were put into blast in March 1884 and April 1886. They are 18·20 metres high, 4·40 diameter at the furnace-mouth, 6 metres at the top of the bosh, and 2·20 m. in the hearth. Each is furnished with four tuyeres, the blast being heated to 650° C. There are three Whitwell stoves per furnace, each 16 metres high and 6·72 exterior diameter. The phosphorus in the pig produced is from 1½ to 2 per cent., the oolitic ores of Villerupt and Butte being employed in its production. Each furnace produces some 110 tons of forge pig per day.

After seeing these works, the party was conducted, under the guidance of M. le Chevalier Van der Maesen, managing director of the *Société des Mines de Meurthe et Moselle at Villerupt*, over the works of

this Society. These works consist of a single blast-furnace, 21 metres in height, furnished with four Cowper stoves. Foundry pig only is produced, the ores of the neighbourhood being employed. The blowing engine was constructed at Middlesbrough by the Tees-side Company.

At midday, after inspecting the works, the members and foreign visitors were entertained at lunch at Micheville, where *déjeûner*, provided by the *Maîtres de Forge du Groupe de Longwy*, was served, the chair being taken by Mons. le Comte de Saintignon.

The *Hauts-fourneaux de Micheville* (Messrs. Ferry, Curicque, & Co.) consist of two blast-furnaces and a foundry. The blast-furnaces are the largest in the neighbourhood, producing 140 tons of forge pig, or 85 tons of foundry pig, per day. The Whitwell stoves formerly employed have been lately replaced by Cowper stoves. Ore from a neighbouring concession, and the *minette* ore from Luxembourg, are employed.

At two o'clock the members again entered the special train *en route* for Longwy, on arriving at which town they divided themselves into two sections, one section visiting the blast-furnaces at Senelle, the other section visiting those of M. le Comte de Saintignon, and of *La Société des Hauts-fourneaux de la Chiers.*

MM. the Barons d'Huart and Michel Helson acted as guides to members visiting the Senelle Works. These works consist of two blast-furnaces, quite recently constructed, with the necessary accessories. The furnaces are 18·20 metres in height, 5 metres in diameter at the throat, 5·46 metres in diameter at the top of the bosh, which is about 8 metres above the ground-level; the diameter of the hearth is 2·20 metres, and the axis of the tuyeres 1·35 metre above the ground-level. There are two vertical blowing engines by Bayenthal of Cologne; the furnaces are open-topped, with one central tube for carrying off the gases, 2 metres in diameter, and extending 2·75 metres into the furnace. There are four Whitwell stoves per furnace, each 6·70 metres in diameter and 20 metres high. The air is heated to about 800° C., and arrives at the tuyeres at about 750° C. For each furnace there are five cylindrical boilers, of which three or four only are required at a time, each having 100 square metres of heating surface. The production per furnace is about 80 tons per day for foundry, and 120 tons for forge pig. The consumption of coke per ton of pig is about 1250 kilos. of Belgian coke, containing 13 per cent. ash, with a burden of ore containing

30 per cent. of iron, the blast being heated to 750° C., at a pressure of 18 centimetres of mercury.

At the works of Messrs. Saintignon & Co. there are two blast-furnaces with open tops, with Cowper stoves 18 metres high by 6·40 metres in diameter, the blast being heated to from 750° to 800° C. MM. Saintignon & Co. are the inventors of an improved pyrometer actuated by means of a current of water for measuring the temperature of the blast at the tuyeres. Each furnace is provided with four copper tuyeres, each 160 millimetres in diameter. The coke employed comes from Belgium; it contains 13 per cent. ash. About 1230 kilos. per ton of No. 3 iron produced are required when working with a burden containing $29\frac{1}{2}$ per cent of iron.

At the works of *La Société des Hauts-fourneaux de la Chiers* there are two large blast-furnaces of 6·50 and 7 metres in diameter, respectively, at the top of the bosh, and 19·50 metres in height. They are together capable of producing 200 tons of foundry pig, or 250 tons of forge pig, per 24 hours. Each is furnished with four Cowper-Siemens stoves of 17·50 metres in height, two steam lifts, two vertical blowing engines, system Cockerill, with two steam cylinders and one air cylinder of 3 metres in diameter and 2·40 metres stroke. There are nine boilers with double tubes, heated by the waste gases from the furnaces. The ores are obtained from the deposit of Mont-de-Chat, and from the mines of Laroux-Longlaville and La Madeleine.

After leaving the works at Senelle, the party again took the train, and arrived, at 4.30, at Mont-St.-Martin, where the blast-furnaces, converters, and rolling-mills of the Longwy Steelworks were inspected. This large establishment consists of six blast-furnaces of 300 to 480 cubic metres capacity, three on each side of the railway; three basic-lined converters, each of 15 tons capacity, capable of producing 400 tons of ingots per day, and powerful rolling-mills for blooms, rails, billets, sheets, and wire rod. The basic linings of the converters last for 160 to 175 operations, the plugs going from 16 to 25 blows. The dolomite is shrunk in three cupolas, with natural draught, the firing lasting 8 days, the whole charge of the cupola being drawn at one time. The Thomas pig employed in the manufacture of the basic steel is taken molten from the blast-furnace to the converter, and contains from 1·8 to 2 per cent. of manganese, 2 per cent. of phosphorus, from 0·35 to 0·40 per cent. silicon, and 0·05 per cent. sulphur. Manganiferous ores from Nassau are employed in its manufacture. The slag is ground, and sold as a fertiliser, for thirty-six francs per ton at the works. A

large number of very interesting samples were shown by M. Escalle, the manager of the steelworks, and also two diagrams, which are reproduced;* one of these diagrams showing the order of the elimination of the elements in the pig under treatment, and the other the composition of the slag during the operation, this latter showing what M. Escalle thinks is a reduction of oxide of iron in the slag, by the manganese in the ferro-manganese added at the end of the operation.

In the evening, the party were entertained, at the Hôtel de Mont-St.-Martin, at dinner, at which M. le Comte de Saintignon took the chair, supported by M. Dreux, the Managing Director of the Company, and the leading ironmasters of the district. In returning thanks for the cordial reception accorded to them, Mr. Gilchrist hoped that the French and Luxembourg engineers would visit England some time during next May, a proposal which was most enthusiastically received.

On Saturday morning, accompanied by MM. le Comte de Retz, le Comte de Lespinasse, and other gentlemen, the party crossed the frontier into Luxembourg, and arrived at Esch, where they were met by the three Messrs. Metz and by M. Muller, and were by them conducted to the blast-furnaces at Esch. These works comprise four blast-furnaces, with fourteen Cowper stoves and four blowing engines. The annual production of pig is 65,000 tons of forge pig, 30,000 tons of basic pig, and 24,000 tons of foundry pig, or a total of 119,000 tons. After seeing over these works, the party were taken by special train, kindly provided by M. Metz, to Dudelange, where, after lunch, they inspected the works of Messrs. Metz & Co., of which M. Meyer is managing director. These works comprise blast-furnaces, steelworks, and rolling-mills. There are four blast-furnaces, with sixteen Cowper stoves and four blowing engines. There are four converters employed in the production of basic steel. The pig metal employed in the steelworks is all brought in the molten state from the furnaces. The average composition of the pig employed is:—

| Thomas Pig. | White Fracture. | Grey Fracture. |
|---|---|---|
| Silicon | 0·286 | 0·435 |
| Manganese | 1·546 | 1·948 |
| Phosphorus | 2·295 | 2·413 |
| Sulphur | 0.074 | 0 068 |
| Graphite | 1·659 | 1·745 |
| Combined carbon | 2·000 | 1·759 |

The following are the analyses of the Luxembourg ores, quarried at

* See Plates XII. and XIII.

Dudelange, used in the production of Thomas pig, the samples having been dried at 100° C.:—

| | Luxembourg Ores. | | | Manganese Ore. |
|---|---|---|---|---|
| | Minettes Grises. | Minettes Jaunes. | Minettes Rouges. | Mineral de Nassau. |
| Thickness of bed in metres | 3 metres | 2-2·20 m. | 1 metre | ... |
| Silica | 6·62 | 7·22 | 10·78 | 10·82 |
| Ferric oxide | 49·73 | 58·50 | 58·20 | 35·28 |
| Alumina | 5·68 | 6·69 | 5·96 | 7·84 |
| Lime | 15·10 | 8·00 | 6·45 | 1·46 |
| Magnesia | 0·83 | 0·85 | 0·79 | 0·86 |
| Phosphoric acid | 1·79-1·90 | 2·11 | 2·10 | 0·19 |
| Volatile matter | 20·76 | 17·16 | 15·70 | 10·12 |
| Metallic iron | 34·81 | 40·95 | 40·74 | $MnO_2$ 28·51 * |
| Phosphorus | 0·78 | 0·92 | 0·91 | MnO 5·31 * |

The annual production of steel ingots at these works is about 110,000 tons.

The ordinary quality of steel produced has about the following composition:—Carbon, ·06 to ·07 per cent.; phosphorus, ·07 to ·08 per cent.; manganese, ·3 to ·35 per cent. Extra soft material is also produced in which the phosphorus is about ·03 to ·04 per cent.

The after-blow lasts three minutes. 3·5 kilos. of 60 per cent. ferro are added per ton of pig converted.

The basic slag produced has the curious characteristic, which is not met with in other basic slags, of rapidly falling to a flakey powder on cooling. Its composition is:—

| | |
|---|---|
| Silica | 5·85 |
| Protoxide of iron | 14·06 |
| Peroxide of iron | 1·47 |
| Protoxide of manganese | 5·58 |
| Alumina | trace |
| Lime | 53·50 |
| Magnesia | 2·95 |
| Phosphoric acid | 16·69 |
| Sulphur | 0·33 |

The basic linings are rammed, and go 150 blows; the plugs go 22 blows. There are 100 holes in the plugs, 18 mm. diameter at the top, and 20 mm. diameter at the bottom; formerly they only used 80 holes, but they find that with 100 the oxidation is less.

After inspecting the steelworks and rolling-mills, the party re-entered the special train, and were taken by it close to the château of

* Equals 22·18 per cent. metallic manganese.

M. Emile Metz at Dommeldange, where they were hospitably entertained at lunch by M. and Madame Metz.

The party subsequently returned to Longwy, where they finally broke up.

## Excursion to Maubeuge.

A small party of members of the Institute left Paris on Thursday, the 26th, in order to visit some of the works in the Nord. The party was received at Maubeuge by M. Jambille, director-general of the Maubeuge Company, by M. Dumont, *fils*, representing the *Société des Forges de Gustave Dumont et Cie;* by M. Dufer, director of the *Société Anonyme de la fabrique de fer de Maubeuge;* by MM. Victor and Armand Dumont of the Espérance Works; by MM. Jaumain and Freson of the Providence Works; and by MM. Armand Sépulchre of Alnoyl; Morel Sépulchre of Tilleul; Felix Sépulchre of Vezin-Aulnoye, and others.

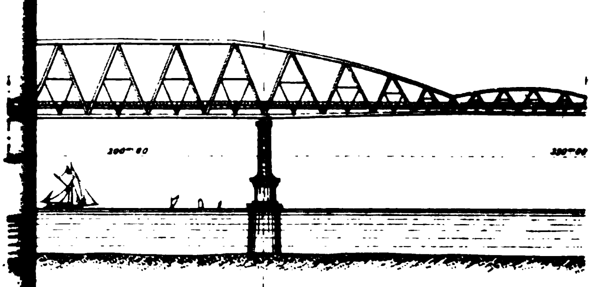
The first works visited were those of the Saint-Marcel at Aulnoye, which are devoted to the manufacture of wrought iron. The party afterwards visited the blast-furnaces, steelworks, and rolling-mills of Providence, where sheets, plates, and merchant iron are produced. The other works visited were those of Maubeuge blast-furnaces, rolling-mills, and foundries; and the works of Tilleuil, belonging to the Vezin-Aulnoye Company at Maubeuge, where merchant iron is produced.

The *Comité des Forges du Nord*, of which M. Martelet is the chairman, entertained the members at luncheon at Tilleuil, when M. Jambille proposed the toast of the Iron and Steel Institute and its President; and among the other toasts given were the forgemasters of the North of France, and the French iron industry

It was proposed that a fifth excursion should be made to the steelworks of Isbergues, in the Pas-de-Calais, but the number of members who gave in their names was so limited that the idea was abandoned.

PLATE I.

CO.'S



Plan of girders seen from above, with the platform and lower bracing removed

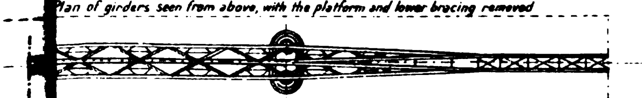


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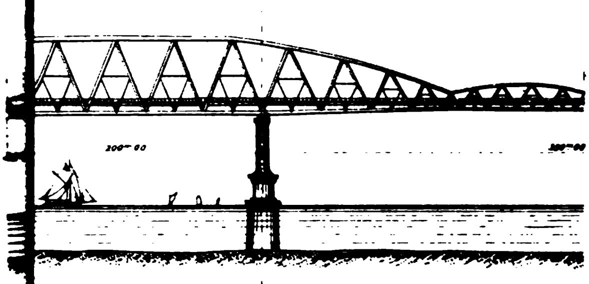
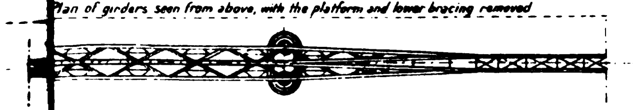
PLATE I.

CO.'S



*Plan of girders seen from above, with the platform and lower bracing removed*



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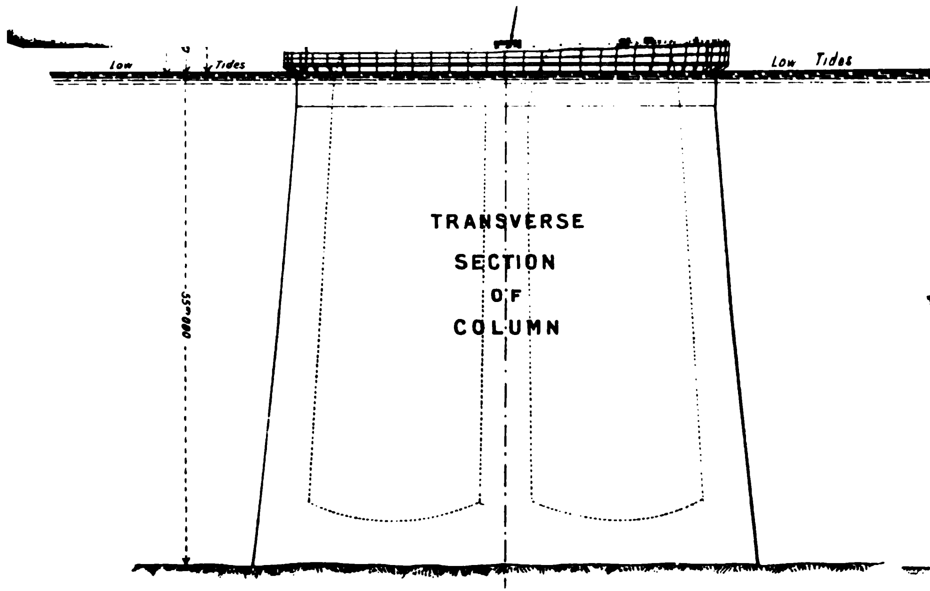
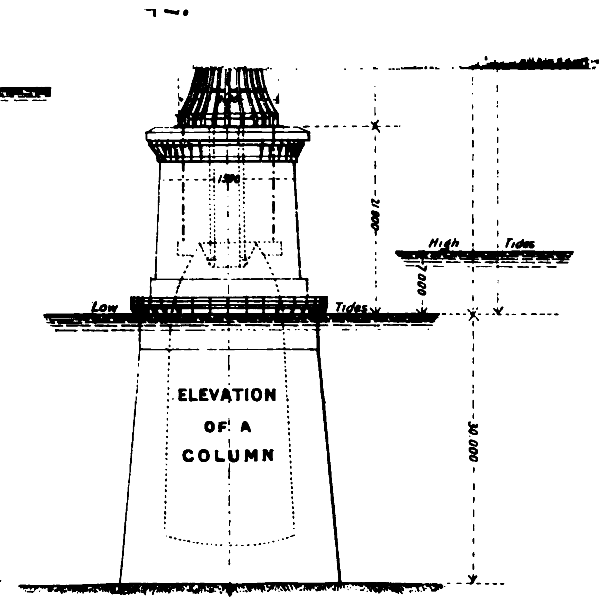



Superstructure—Preliminary Designs.
Spans of 300m. and 500m.




Superstructure—Preliminary Designs.
Spans of 200m. and 350m.



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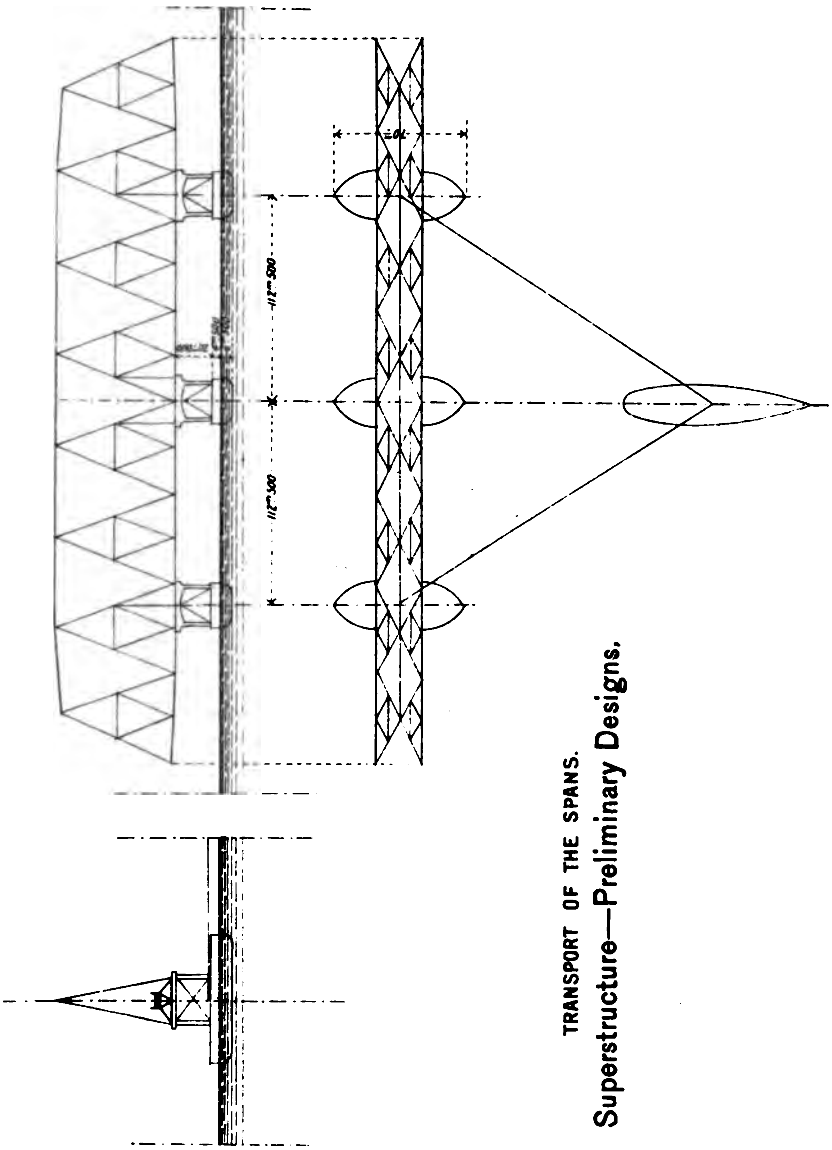
# TO ILLUSTRATE MESSRS. SCHNEIDER & CO.'S PAPER ON THE CHANNEL BRIDGE.



TRANSPORT OF THE SPANS.
Superstructure—Preliminary Designs.



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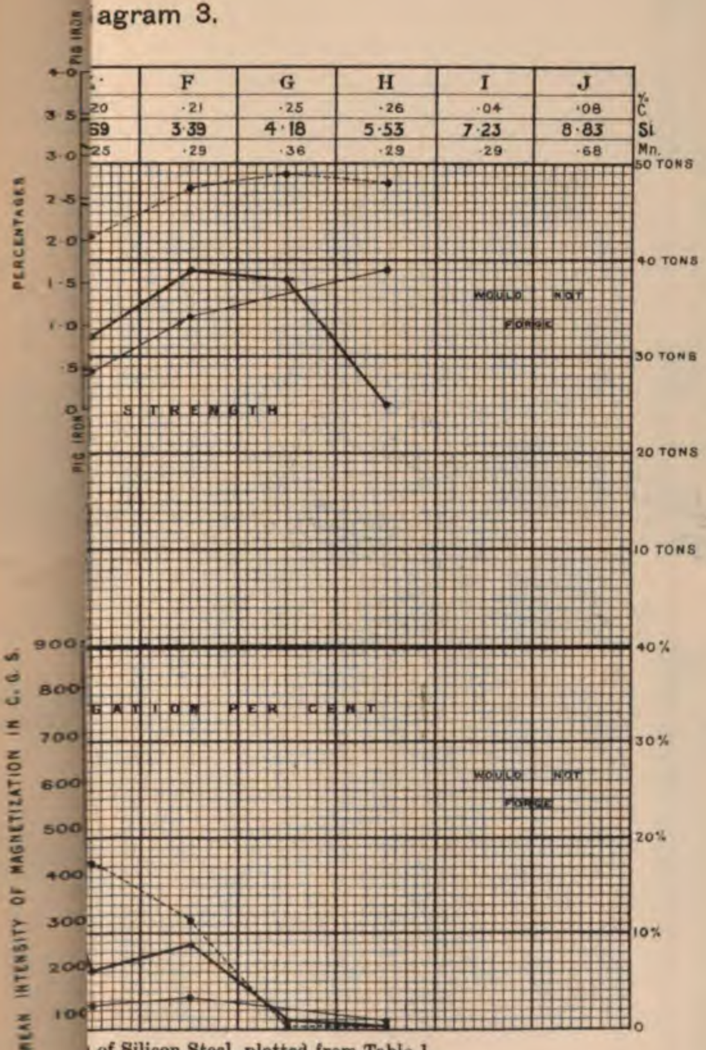
F IRON AND SILICON."

agram 3.




of Silicon Steel, plotted from Table 1.

Annealed test-bars (Hadfield) on 2″ lengths.

Unannealed „ „ „ 2″ „

Annealed „ (Kennedy) „ 10″ „



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PLATE V.

TO ILLUSTRATE MESSRS. HEAD AND POUFF'S PAPER
ON "A NEW FORM OF SIEMENS FURNACE."

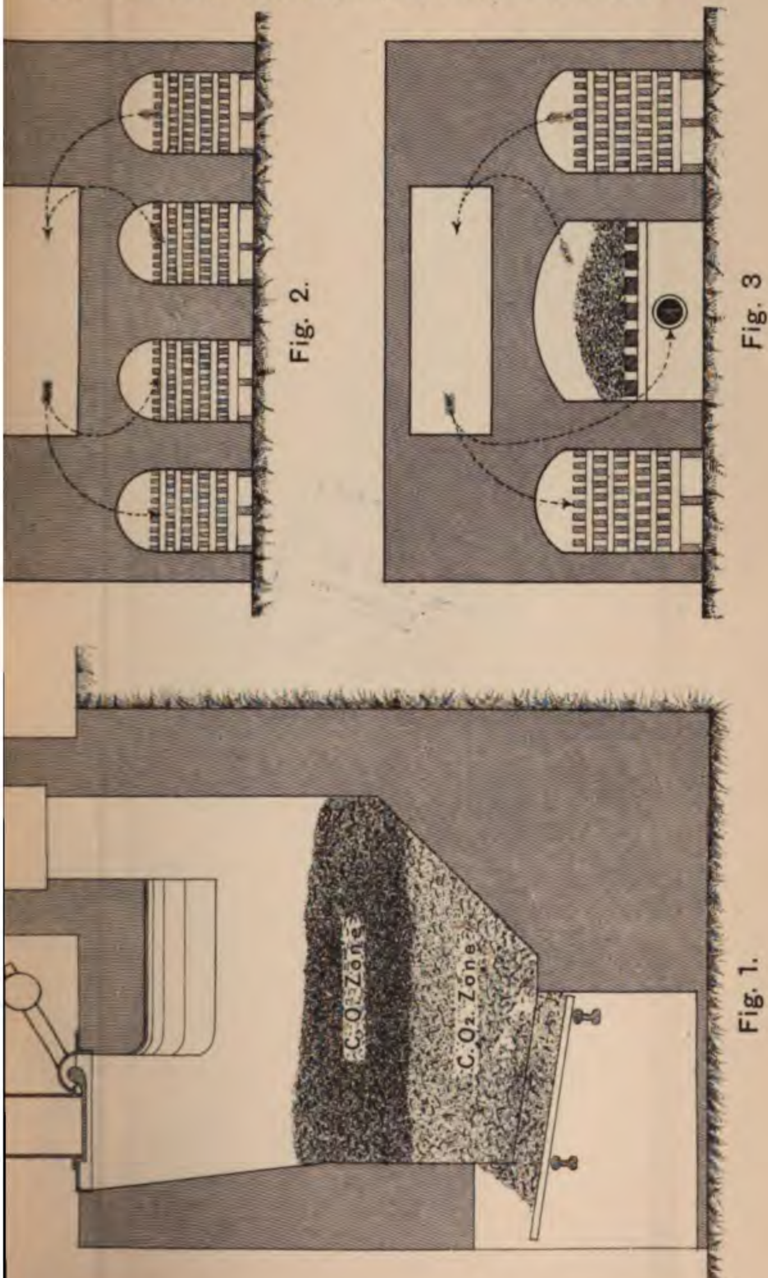


Fig. 2.

Fig. 3

Fig. 1.



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N A NEW FORM OF

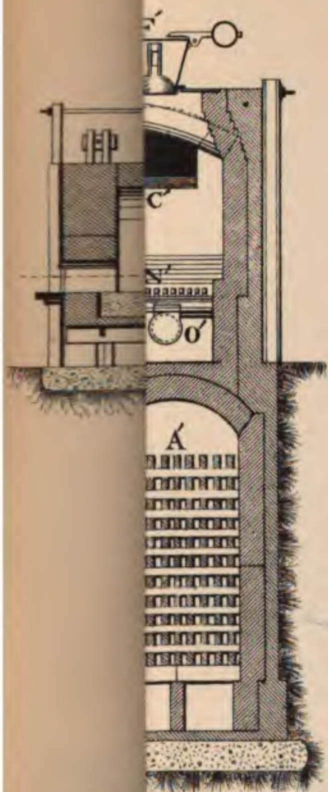
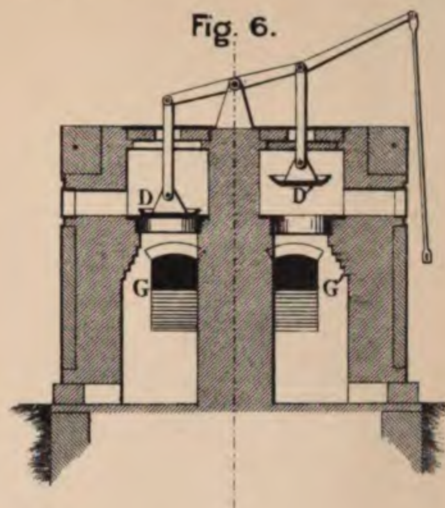



Fig. 6.

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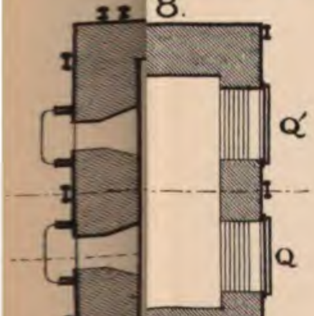


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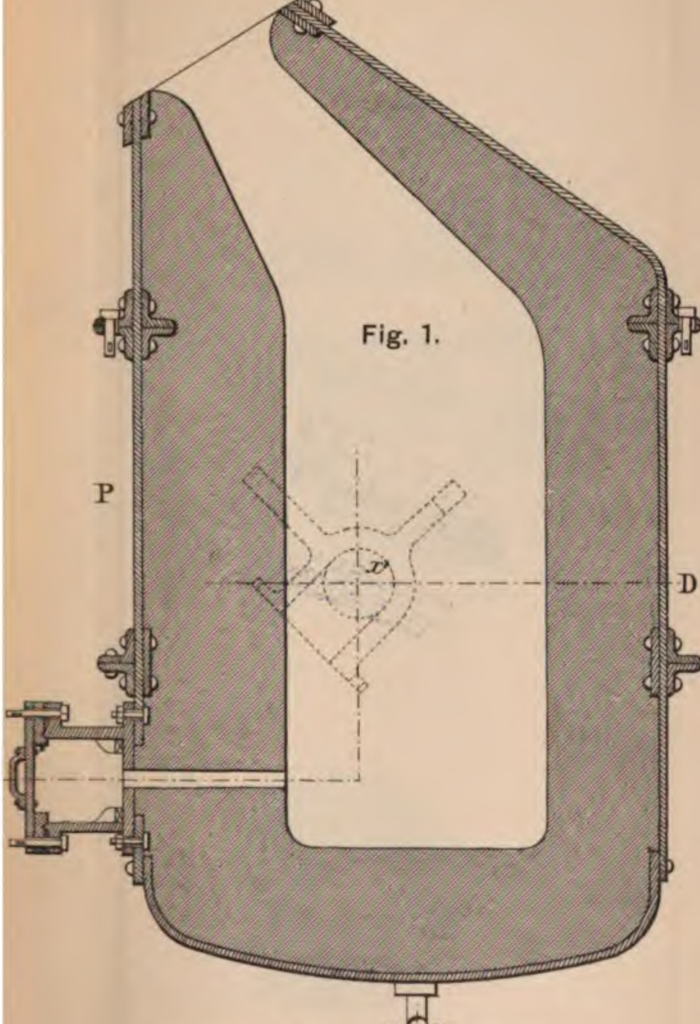
ILLUSTRATE MR. F. L. GARRISON'S PAPER ON "THE ROBERT BESSEMER STEEL PROCESS."




SECTION AT C. D.



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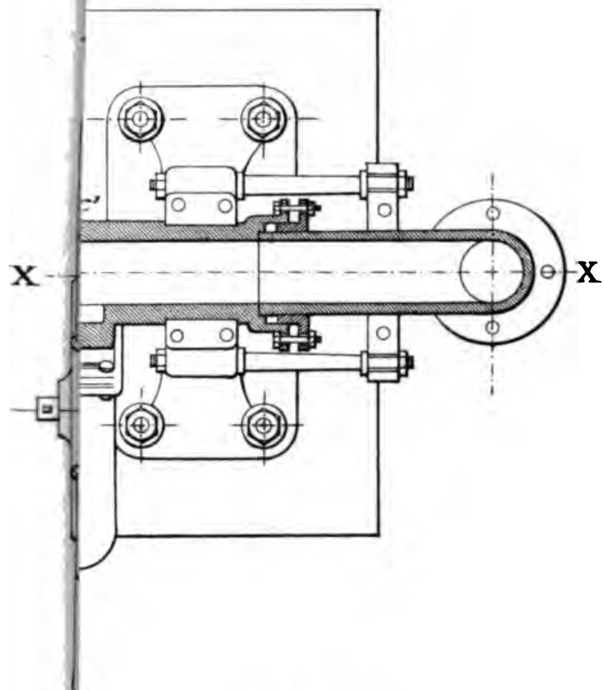


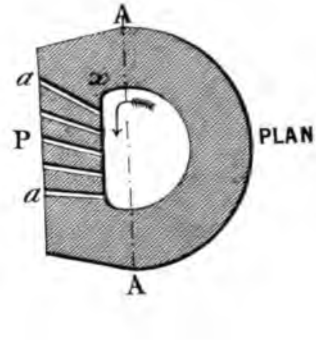



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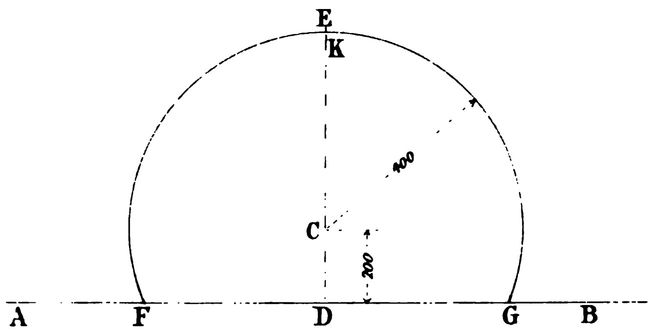
TO ILLUSTRATE MR. F. L. GARRISON'S PAPER ON "THE ROBERT BESSEMER STEEL PROCESS."

Fig. 6.




SECTIONAL

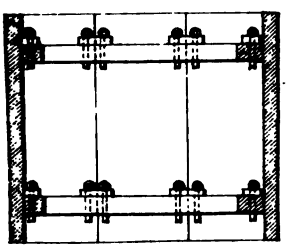


Fig. 7.

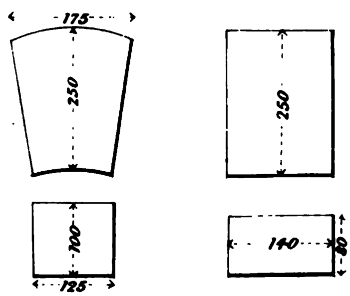
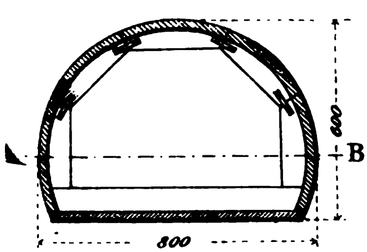



Fig. 8.



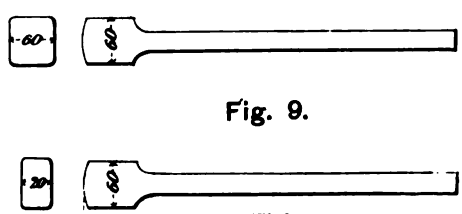




Fig. 9.



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TO ILLUSTRATE MR. F. L. GARRISON'S PAPER ON "THE ROBERT BESSEMER STEEL PROCESS."

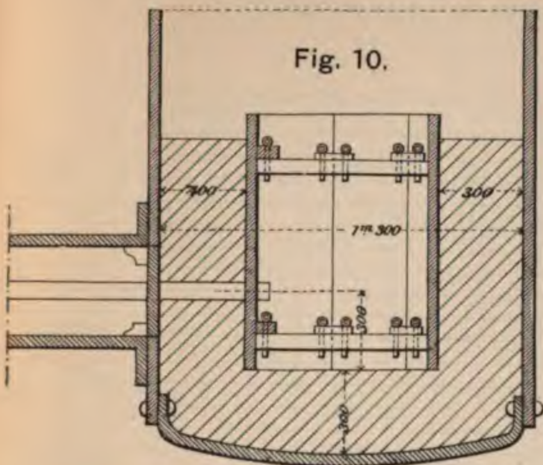


Fig. 10.

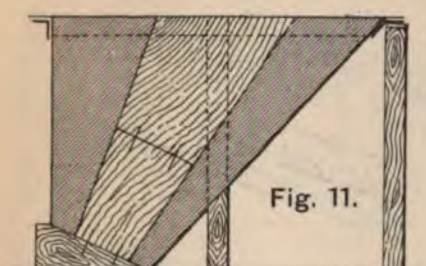

Fig. 12.


Fig. 11.

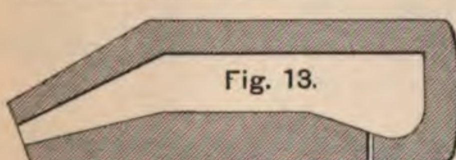

Fig. 13.

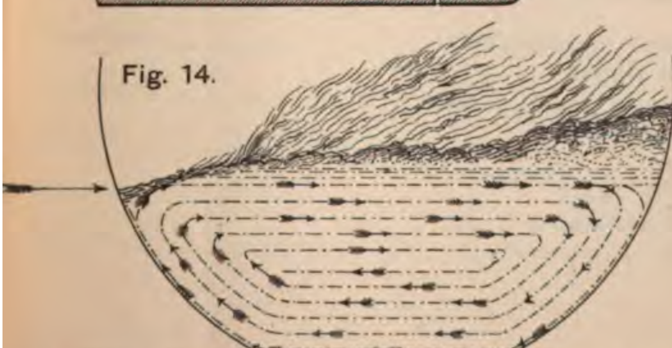

Fig. 14.



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PLATE XI.

# TO ILLUSTRATE THE BASIC BESSEMER PROCESS AT LONGWY STEEL WORKS.

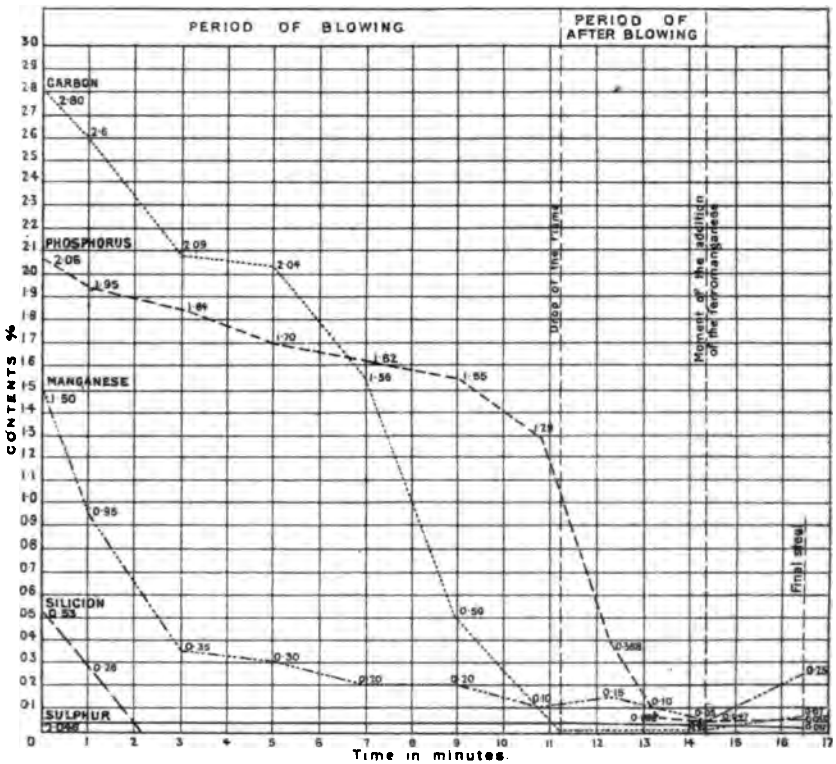



**Diagram showing the course of dephosphoration in the basic Converters.**

Phosphorus

Manganese

Carbon

Silicon

Sulphur

**Operation No. 339 on the 17th August 1889.**

*Addition of 0·5 °/。 ferromanganèse à 63 °/。; Lime 17·5 °/。.*

---

FINAL STEEL.

*Annealed*—**Resist. 38^K.3 A. 29**

*Hardened*— „ **46^K.7 All. 20**



Ballantyne, Hanson & Co. Edinburgh & London.

PLATE IX.

TO ILLUSTRATE MR. F. L. GARRISON'S PAPER ON "THE ROBERT BESSEMER STEEL PROCESS."

Fig. 6.

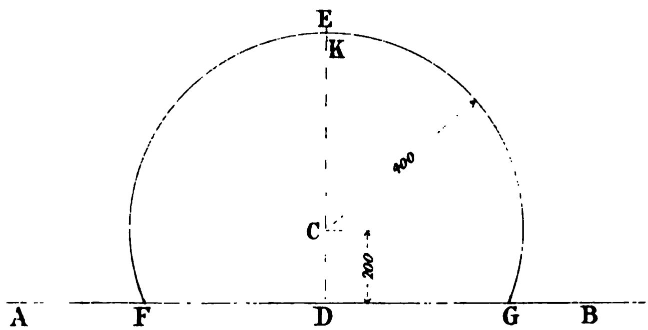
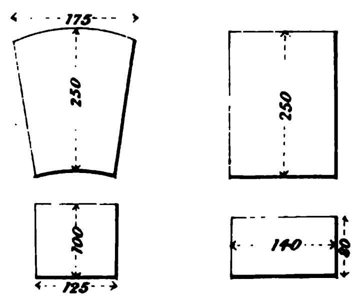



Fig. 7.




SECTIONAL

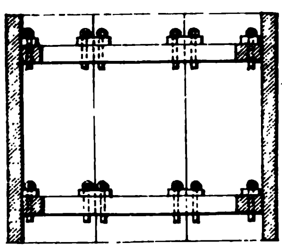
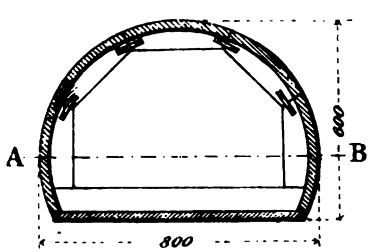


Fig. 8.



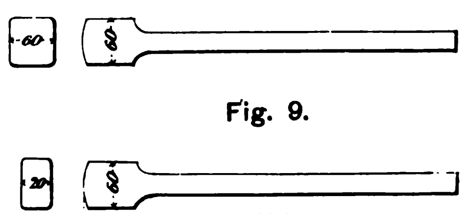




Fig. 9.



Ballantyne, Hanson & Co. Edinburgh & London.

# NOTES

ON THE PROGRESS OF THE

# HOME AND FOREIGN IRON AND STEEL INDUSTRIES.

II.—1889.

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ABSTRACTORS.

EDWIN J. BALL, Ph.D.

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# IRON ORES.

## CONTENTS.



## I.—*OCCURRENCE AND COMPOSITION.*

**Geological History of Iron Ores.**—A valuable contribution to the geological history of iron ores has recently been made by Mr. W. H. Hudleston.* An iron ore is defined as a mixture of oxides or salts of iron with earthy or carbonaceous impurities, and containing from 72 per cent. of iron downwards. Excluding sulphur compounds, there are only four minerals of importance, namely, magnetite, hæmatite, limonite, and chalybite. Iron is probably the prevailing element in the solar system; meteorites show that there is abundance of iron in Kosmos, so that it probably exists to a large extent in the centre of the earth. The most abundant iron silicates are mica, hornblende, and augite, and next come olivine and hypersthene. These minerals are variously acted on by carbonic acid. By studying the relation of iron to oxygen, and, secondly, the action of carbon products upon these elements, the conclusion is arrived at that a large proportion of iron ores is engendered by vegetable decomposition, such processes acting as accumulators of the ore itself. The reactions are illustrated in the formation of bog ore. Iron bicarbonate dissolved in the water is decomposed by oxygen, the oxide becomes hydrated and sinks. Then again, decomposing organic matter abstracts the oxygen, and so the solution and precipitation is kept up indefinitely till some cause leads

* *Proceedings of the Geologists' Association*, vol. xi. pp. 104–144.

to a preponderance of the one or other. If the balance is in favour of decomposition, then there is an accumulation of ore.

Most iron ores must be regarded as bedded accumulations, in spite of the large quantities found in mineral veins. The following table shows the production of iron ore in Great Britain for 1881, arranged according to the respective geological formations :—

| | Tons. | Tons. |
|---|---|---|
| A. Tertiary iron ores (Ireland) | | 200,000 |
| B. Iron ores of Jurassic age— | | |
| Cleveland | 6,538,000 | |
| Northamptonshire | 1,270,000 | |
| Lincolnshire | 1,020,000 | |
| Other districts | 148,000 | |
| | | 8,976,000 |
| C. Iron ores of Permian age— | | |
| Lancashire | 1,190,000 | |
| Cumberland | 1,615,000 | |
| | | 2,805,000 |
| D. Coal Measure iron ores— | | |
| England | 2,540,000 | |
| Wales | 278,000 | |
| Scotland | 2,600,000 | |
| | | 5,418,000 |
| E. Iron ores older than Coal Measures | | 238,000 |
| Total in tons of ore | | 17,637,000 |

Under E. most of the ores are crystalline, and are chiefly mere vein products. The iron ores of the Coal Measures are principally clay ironstone and blackband ironstone, which must be classed as carbonates, and also some brown ore or limonite. The Permian ores are chiefly hæmatites, and the Jurassic ores mainly carbonates and limonites. A similar table is given for the United States.

*Recent Iron Ores.*—The humus acid of the soil is always busy dissolving and reducing iron combinations, and the solutions are transported till they are stopped by an impervious bed. An interesting illustration of this is seen in the Bagshot district, and in the Erradale deposit of limonite in Ross-shire. The most interesting and important are the lake deposits, where iron is dissolved out from the rocks and deposited as limonite in lakes where the oxidizing influences, above referred to, preponderate. The deposition of these ores has often been ascribed to the action of *Gallionella ferruginea* and other diatoms, but there seems to be a balance of evidence against this theory. A similar power of iron secretion has been ascribed to certain encrinites, but it is most probable that a theory of replacement is to be preferred to one of secretion.

*Tertiary Iron Ores.*—Extensive bog deposits have been formed at the base of the Cascade range in America in recent times, and a similar deposit of Tertiary age is seen in the Prosser Mine in Oregon. The most noted Tertiary ores in the British Isles are those of Antrim, and they are associated with basalt like the preceding deposits.

*Cretaceous Iron Ores.*—In the British Isles no deposits of importance occur in the Cretaceous series, but to this age belongs the deposit at Somorrostro, near Bilbao. The iron ores at Tealby and Claxby occur in the Middle Neocomian.

*Jurassic Iron Ores.*—In this horizon there are three main divisions: the Yorkshire Dogger and its equivalents, resting on the Upper Lias; the marlstone of the Middle Lias; and the Frodingham deposits in the Lower Lias. The Dogger ores are traced through Yorkshire, the Peak district, and Northamptonshire, and in all cases there is decided evidence of the substitution of calcareous by ferruginous material. Thick fossil shells sometimes show an inner layer of calcium carbonate, and the oolitic ores are evidently formed by the same substitution. The conversion of calcium carbonate into carbonate of iron diminishes the volume and so increases the porosity; this favours the oxidation of the ores, as in the Northampton ore. The source of the iron is more doubtful; much has probably come from the Lias clays and Coal-Measure shales. Similar remarks apply to the Cleveland and Frodingham iron ores, but in the case of the Cleveland ores the matter is not quite so clear.

*Permian Iron Ores.*—Many of the ores here considered lie below the Coal Measures, but are mainly of Permian age. The ore bodies are the result of replacement of limestone by hæmatite and not of deposition in open chambers or caverns. Faulting has greatly determined the position of the deposits. The ferrugination probably took place between the deposition of the "Whitehaven Sandstone" and the basal Permian conglomerate, *i.e.*, in the interval between the close of the Carboniferous and the beginning of the Permian. The author is inclined to believe in hot springs as the agent of deposition.

*Other British Iron Ores.*—The clay ironstones of the Coal Measures seem to show original concretions in strata where carbonate of iron was more abundant than carbonate of lime, and the usual process of deposition in estuarine beds was here effected on an immense scale. The proximity of coal, blackband ironstone, &c., seems to show deposition in lagoons where coal-forming matter did not greatly abound.

There are no ironstones largely worked below the Coal Measures, except those of Permian age, which have been already noticed.

In America the case is different, as very large deposits occur in rocks certainly older than the Coal Measures. The great ore-producing horizons are the Laurentian, Huronian, and Silurian groups. In Europe the Gellivara and Kirrunavara deposits lie in the Archæan series. The Swedish ores are considered to be hæmatites reduced to magnetites, whilst there is a prevailing impression to the contrary with the Archæan ores of the United States. The behaviour of iron in eruptive rocks seems to show that magnetite is the original form of iron ore, though this may not be applicable to large masses. The question here really becomes: what have been the causes of concentration? The action of organic acid has been probably replaced by silicic acid in these older beds, but one thing is tolerably certain, that the more modern deposits have been produced by the leaching action of acids, mostly of organic origin, together with the oxygenating water as a rival agent.

**Mangano-Magnesian Magnetite.**—Mr. A. H. Chester * describes an iron black mineral, said to be chrome iron, from New Zealand, where it occurs in association with serpentine. On analysis it yielded:—

| $Fe_2O_3$. | $Mn_2O_3$. | FeO. | MnO. | MgO. | Sp. gr. |
|---|---|---|---|---|---|
| 69·70 | 3·32 | 20·50 | 1·50 | 4·98 | 4·67 |

The mineral is thus a magnetite, in which part of the ferric oxide is replaced by manganic oxide, and part of the ferrous oxide by manganous and magnesium oxides. It may be called a mangano-magnesian magnetite, a variety not noticed heretofore.

**The Iron Ores of France.**—Iron ore occurs in forty Departments of France. In the Department of the Meurthe-et-Moselle, large deposits of brown iron ore are found; brown iron ore also occurs in the Department of Ariège, red hæmatite occurring in the Pyrenees. Only about one-half the ore requirements of the French blast furnaces are obtained from France proper, the other part consisting mainly of specular ore from Elba, and the magnetites from the Province of Constantine in Algiers and Mokta-el-Hadid, San Leone in Sardinia, Spain, Lorraine, and Luxemburg. The imports of iron ore are increasing

* *Mineralogical Magazine*, vol. viii. pp. 125–126.

annually, whilst the output in France itself is steadily diminishing, as will be seen from the following table :—

| Year. | Output. | Value. | Workpeople employed. |
|---|---|---|---|
| | Tons. | Francs. | |
| 1836 | 2,275,000 | 4,988,000 | 13,042 |
| 1846 | 3,008,000 | 7,768,000 | 12,870 |
| 1856 | 4,608,000 | 16,455,000 | 20,534 |
| 1866 | 3,790,000 | 13,626,000 | 12,263 |
| 1876 | 2,393,000 | 13,371,000 | 9,296 |
| 1886 | 1,999,000 | 6,915,000 | 5,411 |

The ores from the Department of Meurthe-et-Moselle supply a large part of the blast furnaces of North-East France. The Micheville mines, 10½ miles from Longwy, afford a good example of the mode of occurrence of the ore in this Department. The ore found is an oolitic ironstone, and three different kinds are won :—

(1.) An upper calcareous deposit, 8 feet 4 inches in thickness, poor in iron, the composition being as follows :—

| Silica. | Alumina. | Lime. | Iron. | Phosphoric Anhydride. |
|---|---|---|---|---|
| 13·40 | 6·70 | 18·80 | 27·02 | 1·16 |

(2.) A second bed, 6 feet 6 inches thick, of which the following is an average analysis :—

| Silica. | Alumina. | Lime. | Iron. | Phosphoric Anhydride. |
|---|---|---|---|---|
| 15·85 | 6·87 | 4·77 | 40·80 | 1·45 |

(3.) A third and still lower bed, 5 feet thick, having the following composition :—

| Silica. | Alumina. | Lime. | Iron. | Phosphoric Anhydride. |
|---|---|---|---|---|
| 13·23 | 7·07 | 7·24 | 39·80 | 1·46 |

The second or intermediary deposit is the one chiefly worked, as this ore is found to give the best results in the blast furnace. Over 100,000 tons a year are raised from this bed.

At Dielette, on the coast of Normandy, six beds of iron ore have been found. These vary in thickness from 10 feet to 46 feet. Altogether the net quantity of ore at present available in these beds is over 70,000,000 tons. The following is an analysis of the ore :—

| $Fe_2O_3$. | FeO. | MnO. | MgO. | CaO. | $Al_2O_3$. | $SiO_2$. | $P_2O_5$. | Loss. |
|---|---|---|---|---|---|---|---|---|
| 66·24 | 12·62 | 0·89 | 1·79 | 2·45 | 3·94 | 10·22 | 1·00 | 0·66 |

The ore occurs in a number of parallel beds of iron ore and quartzite adjoining granite. They are worked by a vertical shaft from which a

cross-cut has been driven seawards to cut the nearly vertical ore beds. The shaft is 307 feet deep, and the cross-cut has been driven over 800 feet. Six ore beds have been already met with, and more will probably be found.*

M. H. Guillery † also describes the ores occurring at Dielette. The ore is, he states, a crystalline mixture of red hæmatite and magnetite, and gives on analysis:—

| Fe. | Mn. | P. | $SiO_2$. | $Al_2O_3$. | CaO and MgO. |
|---|---|---|---|---|---|
| 57·36 | 0·071 | 0·24 | 11·87 | 2·30 | 3·20 |

The present production is 150 to 200 tons daily, costing 6s. 5d. per ton.

**The Iron Ore Resources of Meurthe-et-Moselle.**—H. Rémaury ‡ gives a careful summary of the iron ore resources of Meurthe-et-Moselle. The geological constitution of the Department is confined to stratified rocks, which are deposited in a constant succession, and which dip towards the Paris basin at the rate of 1 in 50. The deposit of oolitic iron ore is situated at the contact of liassic argillaceous marls and limestone beds of the inferior oolite. It is the most important of all the mineral deposits in France. The ore is a hydrated oxide of iron, with an argillaceous or calcareous gangue. The deposit has a mean width of 12 miles and a length of more than 60 miles. The best ore contains 34 to 36 per cent. of iron and has a fusible gangue. Calcareous ores containing less than 30 per cent. are employed as flux. Phosphorus is always present in the ores, the percentage amounting to 0·2 to 1·0.

The author describes the various mines in detail, giving analyses of the ores and sections of the strata. The ore costs on an average 2s. per ton to mine, and it costs at the furnace 2s. 6d. to 3s. 4d. per ton. It may be estimated that the total extent of the concessions of the three groups of Nancy, Longwy, and Briey do not fall short of 98,800 acres. The production is more than two-thirds of the total quantity raised in France. In 1887 it amounted to 1,953,290 tons. The maximum was reached in 1882 when the production amounted to as much as 2,160,000 tons.

* *Stahl und Eisen*, vol. ix. p. 852.

† *La Métallurgie*, vol. xx. pp. 933–934.

‡ *Mémoires de la Société des Ingénieurs Civils*, vol. xlii. pp. 64–104.

**Chrome Iron Ore from Orsova.**—The chrome iron ore found in the serpentine, occurring near Orsova, on the Danube, has, according to A. Gouvy,* the following composition :—

| $Cr_2O_3$. | $F_2O$. | $Al_2O_3$. | CaO. | MgO. | $SiO_2$. | Total. |
|---|---|---|---|---|---|---|
| 38·95 | 16·13 | 17·50 | 2·20 | 17·20 | 8·00 | 99·98 |

In another sample the percentage of alumina reached 27·75.

Messrs. Gauss Brothers, of Vienna, are erecting near Orsova a works for the manufacture of ferro-chrome from the chrome iron ore found in that neighbourhood. This ore has the following percentage composition :—

| $Cr_2O_3$. | $Fe_2O_3$. | $Al_2O_3$. | MgO. | CaO. | $SiO_2$. |
|---|---|---|---|---|---|
| 53·00 | 35·32 | 8·20 | 2·00 | trace | 2·40 |

A number of other analyses are also published by R. Busek.†

**Iron Ore from Mont Ara.**—The following are analyses of Spanish iron ores exhibited at the Paris Exhibition by the Bidassoa Railway and Mining Company, Irun :—

| | Brown Hæmatite. | Brown Hæmatite. | Spathic Ore. |
|---|---|---|---|
| | Per cent. | Per cent. | Per cent. |
| Ferric oxide | 78·72 | 81·81 | 5·86 |
| Ferrous oxide | ... | ... | 48·86 |
| Manganese oxide | 2·51 | 2·64 | 5·61 |
| Alumina | 1·19 | 0·20 | 0·70 |
| Lime | 0·61 | 0·63 | 0·21 |
| Magnesia | ... | ... | 1·08 |
| Phosphorus | ... | ... | ... |
| Sulphur | 0·10 | 0·12 | 0·10 |
| Silica | 5·87 | 3·25 | 1·84 |
| Carbonic anhydride | ... | ... | 34·95 |
| Moisture and organic matter | 11·00 | 11·25 | 1·50 |
| Metallic iron | 55·09 | 57·25 | 41·55 |
| Metallic manganese | 1·94 | 2·04 | 4·35 |
| Moisture | 3·01 | 8·37 | 0·11 |

A partial analysis of roasted spathic ore showed 56 per cent. of iron and 6 per cent. of manganese.

**Magnetite in North Sweden and in the Ural.**—H. von Schwarze ‡ points out in what respects the magnetite mountains of North Sweden differ from those of the Siberian Ural, and in what respects they are similar.

* *Stahl und Eisen*, vol. ix. p. 398.

† *Ibid.*, vol. ix. p. 729.

‡ *Zeitschrift des Vereines deutscher Ingenieure*, vol. xxxiii. pp. 783–785.

The most southerly of the magnetite mountains of North Sweden is that of Gellivara, which is situated below the 67th degree of latitude. The mountain character is here least striking. The magnetite crops out only in the form of narrow ridges above a high plateau with a gradual inclination. The ore is very strongly magnetic; it is associated with apatite, and in places contains as much as 5 per cent. of red hæmatite. It is assumed that the ore was originally phosphoretted red hæmatite that has gradually become converted into magnetic oxide, whilst the phosphoric acid and the lime have crystallised out as apatite. The Gellivara ore averages 60 to 70 per cent. of iron, and 0·1 to 1·7 per cent. of phosphorus. The percentage of sulphur is quite inconsiderable. The ore, too, contains very little manganese; but titanium occurs in places up to nearly 2 per cent.

The most remarkable iron ore deposits of Sweden are those of the Kirrunavara and the Luossavara mountains, which are separated by a small lake, and which are situated below the 68th degree of latitude. The Kirrunavara mountain rises 600 feet above the surrounding plateau, and it extends longitudinally for 13,700 feet. While the back, which trends approximately north and south, consists of uncovered iron ore, the sides are covered with sand and debris. The ore dips towards the east, the thickness of the magnetite amounting to as much as 710 feet of pure ore. The best sample yielded 73·5 per cent. of pig iron, and the poorest 62 per cent. The northern and southern portion contains not more than 0·04 per cent. of phosphorus, whilst the central portion contains 1·3 per cent. The quantity of ore in sight is enormous. The back contains 86,127,000 tons; the portion covered with sand above the plateau contains 174,331,700 tons. For each metre of depth below the surface, there may be reckoned 1,510,000 tons of ore.

The Luossavara mountain exhibits the same characteristics as the Kirrunavara mountain. It is, however, not so imposing, being more conical in shape. The quantity of ore above the surface amounts to 27,656,000 tons, and each metre of depth below the level of the valley will yield 239,000 tons of magnetite. The quantity of ore available is thus not so great as in the two other mountains mentioned. The ore, however, is better adapted for the Bessemer process. The yield of pig iron varies from 70 to 73 per cent., and the percentage of phosphorus is as low as 0·003. The total amount of Bessemer ore available in the two mountains above the level of the valley may be estimated at 85,000,000 tons.

Unlike the Swedish iron mountains, the iron ore deposits of the Siberian Ural have been worked for 150 years. The most important deposit, that of Blagodat, is situated near Kuschwa, a station of the Perm-Yekaterinburg railway. At the present time, it rises to a height of 500 feet above the river Salda. It was formerly considerably higher. Mining is not carried on so energetically as formerly was the case; but the requirements of three blast furnaces are still supplied. Whereas the Swedish magnetites are never found to exhibit positive magnetism, this is the case at the Blagodat to a remarkable extent. The ore contains about 65 per cent. of iron, and phosphorus is present only in traces. The surrounding rock is porphyry. Strange to say, the transition mineral is not red hæmatite, as in Sweden, but brown hæmatite.

The second Siberian magnetite mountain is situated in the vicinity of Nizhni-Taghilsk, also on the Perm-Yekaterinburg railway. It has, in so far as it consists of magnetite, been almost entirely worked away. Originally, it was longer and broader than the Blagodat deposit. Extensive mining operations are carried on by Prince Demidoff. The works extend to a depth of 200 feet below the surface, and more than 200 horses bring the ore up by winding paths to the surface. The containing rock is diorite. At the surface, the magnetite is converted into brown hæmatite, and, in the deep workings, into red hæmatite. The ore contains 65 per cent. of iron, and 0·05 per cent. of copper. The mountain is bisected by a bed of mica-schist, containing 2 to 3 per cent. of copper. The bed being 60 to 90 yards in thickness, the copper ore is mined with profit. It is a curious fact that in the vicinity of the Swedish mountains, Kirrunavara and Luossovara, copper ores associated with mica-schist also occur.

**Luxemburg and Russian Iron Ores.**—The following are analyses of iron ores from Luxemburg :—

| | 1. | 2. | 3. | 4. | 5. |
|---|---|---|---|---|---|
| Iron | 33·38 | 36·31 | 35·40 | 38·00 | 30·00 |
| Silica | 7·07 | 8·71 | 16·25 | 13·00 | 5·75 |
| Lime | 16·26 | 12·12 | 10·00 | 8·50 | 19·50 |
| Alumina | 6·42 | 5·13 | 5·45 | 6·70 | 4·20 |

No. 1 contains 1·64 per cent. of phosphoric anhydride.*

* *Stahl und Eisen*, vol. ix. p. 857.

The composition of the red hæmatite from Krivoi-Rog, Russia, is as follows:—

| $SiO_2+Al_2O_3$. | Fe. | S. | P. |
|---|---|---|---|
| 1·40 | 67·60 | 0·01 | 0·033 |

**The Italian Iron Ore Mines.**—A general review of the Italian iron industry is given by C. Helson.* Italy is comparatively rich in iron ore deposits, for they are found in Lombardy, Piedmont, Calabria, Sardinia, Tuscany, and Elba; but at the present time, Lombardy, Elba, and to a certain extent Sardinia, are the only really productive districts. The author gives a map of the island of Elba, and also a series of curves showing the production for each mine, the quantity exported, and the cost of the mineral from 1851 to 1881. Tables are also given showing the details of cost for each mine and for each quantity of ore. It seems, however, that Elban iron ores are within a measurable distance of exhaustion. An estimate in 1879 put down the total reserve of ore as seven and a half million tons, and this will be exhausted at the present rate of consumption within the next thirty years.

The most important of the Sardinian deposits are found in the Silurian schists; they are also found in the granite, and consist of magnetites and hæmatites. The ores are generally purer at some distance from the point of contact of the schist and granite. At present the expenses of transportation have precluded large operations. Seven centres have already been worked, the most important being at San Leone. Average analyses of the ore from this district show:—

| $SiO_2$. | $Al_2O_3$. | CaO. | MgO. | Fe. | Mn. | S. | P. |
|---|---|---|---|---|---|---|---|
| 15–18 | 4·00 | 2·50 | 0·50 | 50–55 | 0·30 | 0·05 | 0·008 |

The mines consist partly of open quarries and partly of underground workings. The ore is lowered by inclined planes to the railway. The output could be brought up to 400 tons daily, but a very much smaller amount is really obtained. Details of other mines are given.

The present difficulties in the way of mining in Sardinia are the cost of transportation, the lack of motive power, and the unhealthiness of the climate.

**Iron Ore in British Columbia.**—In a report to the Director of the Geological Survey of Canada, Mr. G. M. Dawson states that most of the ores hitherto discovered are magnetites, which occur in association with the older metaphoric rocks of the province. Clay ironstone,

* *Le Génie Civil*, vol. xv. pp. 2-5, 22-24.

however, is of frequent occurrence in the coal series of Vancouver and Queen Charlotte Islands, as well as in the tertiary rocks of the interior. The only iron ore deposits which have yet been worked are those of the south-west side of Texada Island, the largest exposures of ore occurring about 3 miles north-west of Gillies Bay. Here the ore mass is from 20 to 25 feet in thickness. It constitutes an irregular contact deposit between limestone and granite. The ore is magnetite of excellent quality, containing nearly 70 per cent. of iron. At the principal deposit of the ore a wharf has been built. The ore is brought down from the quarry to the wharf by an incline, the height of the quarry above sea-level being 250 feet, and the length of the incline ¼ mile. The shipments in 1885 amounted to 190 tons; in 1888 the quantity shipped was 7300 tons, valued at £3680. Magnetite is also found at the Queen Charlotte Islands, the ore being, as a rule, very pure, an exceptionally good specimen yielding on assay 69·88 per cent. of iron. Very pure ore containing 71·57 per cent. of iron was also found at an island in the Walker Group, Queen Charlotte Sound. Other deposits exist at Sooke Harbour, Vancouver's Island, and at a number of other places.

**Iron Ore in Canada.**—Mr. A. Evans, junr.,* states that only one furnace is in blast in Nova Scotia, and none in New Brunswick. The furnace is at the Arcadia Mines, and practically only supplies iron for its own works. Ore seems to be very scarce, and of poor quality, as the following analyses show:—

| | Insoluble. | $P_2O_3$. | $Fe_2O_3$. | FeO. | $Al_2O_3$. | Mn. | CaO. | MgO. | Fe (average). |
|---|---|---|---|---|---|---|---|---|---|
| I. | 5·48 | ... | 51·18 | 2·39 | 2·81 | 1·36 | 2·80 | 4·40 | 31·00 |
| II. | 16·00 | 0·57 | ... | ... | 0·86 | ... | ... | 0·46 | 40·00 |

Sample No. I. was calcareous limonite from the Toten Mine, Londonderry, and No. II. was from the West Mine.

**The Flax-Seed Ore of Wisconsin.**—This remarkable iron ore deposit has been recently described by Mr. J. Birkinbine.† There is, the author observes, probably no place in the United States where a large quantity of iron ore can be mined more cheaply than from the Iron Ridge deposit of Wisconsin.

* *Bulletin of the American Iron and Steel Association*, vol. xxiii. p. 268; *American Manufacturer*, vol. xlv., No. 14.

† *Journal of the United States Association of Charcoal Iron Workers*, vol. viii. pp. 244-250.

A bed of Trenton limestone extends for a considerable distance through Eastern Wisconsin. Immediately below this limestone is found a deposit of Clinton fossil iron ore, generally occurring in small grains loosely cemented by gangue material. The workings of the North-Western Iron Company exhibit this deposit in a most advantageous manner, for the capping of limestone is partially, and in some places entirely absent, whilst the ore shows a thickness of 30 feet.

The following are analyses of the ore :—

| | | | | |
|---|---|---|---|---|
| Metallic iron | 51·09 | 48·82 | 47·32 | 50·96 |
| Phosphorus | 1·19 | 1·21 | 1·50 | 1·48 |
| Silica | 5·48 | 5·66 | 4·16 | 4·60 |
| Lime | 2·82 | 4·77 | 4·17 | 4·66 |
| Alumina | 5·27 | 5·13 | 6·00 | undet. |
| Magnesia | 2·43 | 1·31 | undet. | 2·73 |
| Water | dried | dried | 3·00 | dried |
| Manganese | undet. | ... | trace | trace |
| Sulphur | ... | ... | trace | undet. |

The average composition as determined by the furnace yield is :—

| | |
|---|---|
| Metallic iron | 48·3 |
| Phosphorus | 1·3 |
| Silica | 4·5 |
| Alumina | 5·0 |
| Magnesia | 2·9 |

The ore is practically self-fluxing. From the above it will be seen that the composition of the ore favours its utilisation in producing steel by the basic method. As mined, the ore is in lumps, but these readily break up in handling, or, if exposed to the weather, "slack" into sand composed of fine grains of red hæmatite fossil ore, the size and colour of which have led to the name "flax-seed ore." These grains are held together by a cementing material which was believed to contain most of the lime, silica, and alumina found to be carried by the ore; but some investigations by Mr. F. H. Foote appear to prove that the cementing material, as well as the grains of ore, contain most of the component parts shown by the above analysis. Mr. Foote took samples of the ore for analysis, and then washed portions of them, so as to have only the grains remaining, with little or no cementing material. The first three determinations were made by three different chemists of the ore as mined. They are marked A1, B1, C1. The next three are analyses of the same samples after washing, A2 being the washed ore from A1, B2 the washed ore from B1, &c. :—

| | Ore as Mined. | | | Washed Ore. | | |
|---|---|---|---|---|---|---|
| | A1. | B1. | C1. | A2. | B2. | C2. |
| Iron | 50·95 | 50·10 | undet. | 49·40 | 49·89 | ... |
| Alumina | 2·27 | 4·02 | 4·05 | 2·14 | 3·76 | 3·79 |
| Silica | 3·86 | 4·55 | 4·38 | 4·11 | 4·33 | 4·35 |
| Phosphorus | 1·35 | 0·81 | 1·60 | 1·81 | 0·85 | 1·88 |
| Sulphur | undet. | 0·01 | undet. | undet. | undet. | undet. |
| Lime | undet. | 6·28 | undet. | undet. | 5·66 | undet. |
| Magnesia | undet. | 1·11 | undet. | undet. | 1·36 | undet. |
| Loss on ignition | undet. | 11·19 | undet. | undet. | 11.86 | undet. |
| Moisture | undet. | ... | 1·25 | undet. | ... | 0·67 |

The situation of this deposit, 50 miles north of Milwaukee, 30 miles inland from Lake Michigan, and within 20 miles of Fond du Lac, at the head of Winnebago Lake, makes it accessible, and the cheapness of mining will probably before long bring it into demand. At one time a contract for 1,000,000 tons of this ore was made, and nearly 100,000 tons were mined and shipped in a year.

This deposit probably approaches in extent and resembles somewhat the Minette ore of Luxemburg.

**Alabama Iron Ores.**—Mr. J. H. Pratt * publishes the following analysis of iron ores from the mines of the Bluffton Furnace Company, Alabama:—

| | Clay Bank. | High Bluff. | Boland Bank. | Hickory Tree Bank. | Cleveland-Milliken Bank. |
|---|---|---|---|---|---|
| Ferric oxide | 78·40 | 79·97 | 84·16 | 83·20 | 78·71 |
| Silica | 5·52 | 6·75 | 2·86 | 2·69 | 4·97 |
| Phosphoric anhydride | 1·19 | 2·34 | 2·31 | 2·06 | 2·77 |
| Water, combined | 10·74 | 11·02 | 11·15 | 10·95 | 10·80 |
| Moisture at 100° C. | 0·99 | 0·32 | 0·65 | 0·60 | 0·60 |
| Metallic iron | 54·88 | 55·98 | 58·91 | 58·24 | 55·10 |
| Phosphorus | 0·52 | 1·02 | 1·01 | 0·90 | 1·21 |

**Iron in the Birmingham District.**—Mr. A. F. Brainerd † briefly describes the iron ores, fuel, and blast furnace practice of Birmingham,

* *Iron Age*, vol. xliii. p. 432.

† *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 151–155.

Alabama. As a rule, the raw materials are good, and several record performances have been achieved. The ore deposits run in a north-easterly direction. The Red Mountain, near Birmingham, is the most important outcrop of the Clinton fossil ore. The bed is 10 to 20 feet thick, and contains but little lime until a hundred feet in depth is reached, when it contains 40 or more per cent. The two kinds of ore are mixed for smelting. Most of the coke is made from the Pratt seam, which is 4 to 4½ feet thick. Other coal mines are also worked. Analyses of limestone, ore, and coke are given. One of the ores contains 90·78 per cent. ferric oxide, 5·06 silica, and 0·056 phosphorus, and appears to be a Bessemer ore; it comes from a vein 8 feet thick in Eastern Alabama. The average proportion of ash yielded by the coke is 10 to 12 per cent., but this in some instances is reduced 3 per cent. by more careful manipulation. The mining labour is inferior to that in the north. In conclusion, the author shows that there is no reason for the present prejudice against Southern irons.

**Iron Resources of Gunnison County.**—The iron resources of Gunnison County, Colorado, are dealt with by Mr. R. Chauvenet.* It appears that good ore exists in great quantity in this county. The ores consist chiefly of oxides, the carbonates being rare. The conditions necessary for the manufacture of cheap pig iron are the reasonable proximity, abundance, and purity of the materials, with a scale of wages within two dollars per ton. All these conditions are met with in this district. The most important deposit is known as the "Iron King;" the outcrop is enormous, and extends at intervals for a mile on the mountain side, whence it can be taken on a continuous down grade to the railway. A tunnel shows that about 40 feet could be mined in mass, and about 30 feet more would yield good ore. The deposit occurs in Silurian strata between quartzite and limestone, and is richest near the latter. The ore is magnetite, and contains no titanium nor appreciable quantities of copper. An average sample shows 49·71 per cent. of iron, whilst the best exposures give 67·27 per cent. An analysis gave the following results:—

| $H_2O$. | $SiO_2$. | CaO and MgO. | P. | S. | Fe. |
|---|---|---|---|---|---|
| 0·65 | 3·85 | traces | 0·044 | 0·123 | 58·75 |

The Cumberland claim is similar in character to the Iron King, but

* *Report of the State School of Mines, Golden, Colorado*, pp. 1–26.

at a greater elevation. The transport would thus be more difficult. An analysis of ore from this claim gave the following results:—

| $SiO_2$. | Fe. | CaO. | S. | P. |
|---|---|---|---|---|
| 2·80 | 69·32 | 0·30 | 0·084 | 0·039 |

An immense deposit of titaniferous iron ore exists in the Cebolla district. The lowest analysis shows 9·38, the highest 36 per cent. of titanium. Iron ore is also found in Elkhorn Mountain, and solid manganese ore, containing 52·2 per cent. of manganese in a vein 2 feet thick, is found in Powder-horn Hill. A poor limonite occurs close by, in what appears to be a bedded deposit.

Thirteen miles from the railroad and twenty-seven from Gunnison City, there is a large deposit of manganiferous iron ore of the following composition:—

| | $SiO_2$. | MnO. | $Fe_2O_3$. | CaO. | MgO. | $CO_2$. | Mn. | Fe. |
|---|---|---|---|---|---|---|---|---|
| Unroasted . . | 0·82 | 13·92 | 39·01 | 19·55 | 6·03 | 21·05 | ... | ... |
| Roasted . . . | 1·04 | 17·62 | 49·38 | 24·74 | 7·63 | ... | 13·65 | 34·57 |

A pure limestone is found in numerous localities, with the following composition:—

| Siliceous matter. | $Fe_2O_3$ and $Al_2O_3$. | $CaCO_3$. | MgO. |
|---|---|---|---|
| 1·44 | 0·13 | 98·17 | traces |

Coal of suitable quality is also found at Elkhorn. An estimate of the cost of smelting is given as about £2, 10s. per ton.

**Bog Iron Ore in Colorado.**—An analysis of bog iron ore from Crested Butte, by Prof. R. Chauvenet,* gave the following results:—

| Water and Organic Matter. | $SiO_2$. | $Fe_2O_3$. | $Al_2O_3$. | CaO. | MgO. | P. | Fe. |
|---|---|---|---|---|---|---|---|
| 23·97 | 2·50 | 72·47 | 0·28 | 0·22 | 0·12 | 0·145 | 50·73 |

**Iron and Manganese Ore in Georgia.**—In connection with the sale of iron and manganese mines situated in the vicinity of Cartersville, Georgia,† the following analyses have been made:—

*Grey Specular Ores.*

| | No. 1. | No. 2. |
|---|---|---|
| Metallic iron . . . . . . . . . | 66·283 | 61·496 |
| Phosphorus . . . . . . . . . | 0·024 | 0·012 |

*Brown Ores.*

| | Crow Bank. | Hurricane Mountain. | Wheeler Bank. |
|---|---|---|---|
| Metallic iron . . . . . | 53·371 | 55·697 | 47·470 |
| Phosphorus . . . . . | 1·673 | 0·609 | 0·958 |

* *Report of the State School of Mines, Golden, Colorado*, p. 29.
† *The Age of Steel*, vol. lxvi., No. 13, p. 17.

*Manganese Ores.*

| | Lot 174. | Lot 303. | Lot 306. |
|---|---|---|---|
| Metallic manganese | 47·529 | 55·392 | 41·701 |
| Metallic iron | 4·450 | 0·876 | 2·628 |
| Phosphorus | 0·159 | 0·100 | 0·162 |

**Phosphorus in the Ludington Mine, Michigan.**—Mr. D. H. Browne * has made some 3000 analyses of iron ore from the Ludington Mine, Iron Mountain, Michigan. These analyses were necessary in order to separate the varieties of ore that occurred intermixed in the deposit. The results of the analyses have led the author to discover a method in the distribution of phosphorus through the ore deposit. The results are well exhibited in twenty-three sections, and plans of the mine, on which either figures indicating percentages of phosphorus in the ore removed, or isochemic lines, are shown. The theory of aqueous deposit explains the marked regularity of the isochemic lines and their peculiar curves, the regular decrease of phosphorus from the hanging to the foot-wall of the deposit, and the hydrated, muddy deposit next the foot-wall.

**Iron Ore at Mineville, New York.**—The iron ore deposit at Mineville, in the State of New York, yields a Bessemer ore of great purity, an average sample taken from a pile of about 400 tons showing on assay 72 per cent. of iron and 0·018 of phosphorus. Magnetite crystals of very large size are of frequent occurrence in this ore-body.†

**Tennessee Manganese Ores.**—Mr. J. J. Traver ‡ publishes the following analyses of manganese ores from Carter County, Tennessee:—

| | Manganese. | Iron. | Cobalt. | Copper. | Phosphorus. | Silica. |
|---|---|---|---|---|---|---|
| 1. | 51·57 | 0·25 | 0·916 | ... | 0·253 | 2·05 |
| 2. | 48·91 | 3·42 | ... | trace | 0·216 | 2·50 |

1. From the Blue Spring Vein. 2. From the Taylor Bank.

These and adjacent beds of manganese ore may be traced for miles, but have not hitherto been exploited owing to absence of railway communication. A railway is, however, now in course of construction.

**Texas Iron Fields.**—The only furnace in Texas was built in 1883, and is now worked by convict labour. A report on the iron resources has recently been published, and states that the occurrence of iron

* *American Journal of Science*, vol. xxxvii. pp. 299–310.
† *Iron Age*, vol. xliii. p. 815.
‡ *Ibid.*, vol. xlii. p. 517.

ore is remarkably regular. It is a brown hæmatite, yielding 40 to 45 per cent. when raw, and 50 per cent. when roasted. The ore is easily mined, and gives a satisfactory foundry iron. Limestone of remarkable purity is found. The cost of mining the ore is calculated at 9s. 7d. per ton, and that of producing charcoal pig iron, as verified by the furnace already in operation, at £2, 14s. 2d.*

**Iron Ore in West Virginia.**—Mr. W. N. Page † describes the Glenmore Iron Estate, Greenbrier County, West Virginia. A map and geological section of the district is given. The latter shows an anticlinal at Bob's Ridge, with the strata on each side dipping uniformly to the north-west. The strata are chiefly of Carboniferous and Silurian age. Thirteen workable coal measures have been proved. A persistent seam of iron ore has been traced for six miles on both sides of Bob's Ridge. It varies from 8 to 50 feet in thickness. The ore is an open-structured red oxide, and gives on analysis :—

| $Fe_2O_3$. | $SiO_2$. | MnO. | $H_2O$. | $P_2O_5$. | $SO_3$. | $Al_2O_3$. |
|---|---|---|---|---|---|---|
| 87·15 | 1·98 | trace | 8·50 | 0·12 | 0·10 | 2·5 |

Good limestone, containing 98 per cent. of calcium carbonate, abounds, and the coal is also of good quality. Water-power and timber are close at hand. The cost of production at the furnace is estimated at £2, 5s. 1½d. per ton.

**Virginian Iron Ores.**—Mr. E. C. Pechin ‡ describes the country and iron ores around Buena Vista, Rockridge County, Virginia. The measures are regular, and the outcrop of ore extends over large tracts. One small charcoal furnace has been worked for many years, and it seems that good brown ores can be obtained in sufficient quantities to supply a large coke furnace. Several analyses are given, and show 47 to 57 per cent. of metallic iron, with from 0·15 to 0·39 per cent. of phosphorus. The cost of production is estimated at £1, 19s. 6d. per ton.

**Chilian Manganese Ores.**—In 1868, 54,000 tons of manganese ore for generating chlorine were imported into this country, but this has been reduced to 8000 tons in 1888. Messrs. J. & H. S. Pattinson §

* *American Manufacturer*, vol. xlv. No. 6.

† *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 115-124.

‡ *The Engineering and Mining Journal*, vol. xlviii. pp. 92-93.

§ Paper read before the Chemical Section of the British Association at Newcastle, on September 13, 1889.

show that the ferromanganese industry has given rise to a large demand for rich ores. Manganese ores are now imported from Spain, Portugal, Hungary, Greece, Canada, New Zealand, and Australia, but by far the largest quantities come from Caucasia and Chili. In 1888 the total importation was 85,000 tons, of which 25,000 tons came from Chili. These ores contain a large quantity of protoxide. Several large deposits containing 30 to 40 per cent. of manganese, with a large percentage of calcium carbonate, have been discovered, but as yet only the richer ores have been brought to market.

The following full analyses are given :—

| | | | |
|---|---|---|---|
| Manganese peroxide | 69·23 | 55·06 | 66·03 |
| Manganese protoxide | 11·92 | 23·05 | 10·39 |
| Ferric oxide | 1·67 | 4·71 | 1·50 |
| Lead oxide | 0.09 | 0·06 | 0·05 |
| Copper oxide | 0·15 | none | 0·14 |
| Zinc oxide | 0·10 | none | none |
| Nickel and cobalt | none | none | none |
| Alumina | 4·21 | 2·80 | 1·60 |
| Baryta | none | none | 3·58 |
| Lime | 1·13 | 2·33 | 5·36 |
| Magnesia | 0·24 | 0·56 | 0·13 |
| Potash | 2·86 | 0·46 | 0·15 |
| Soda | 0·08 | 0·26 | 0·11 |
| Silica | 4·17 | 7·30 | 4·75 |
| Carbonic anhydride | none | 0·18 | 2·53 |
| Sulphuric anhydride | 0·05 | 0·13 | 1·57 |
| Phosphoric anhydride | 0·12 | 0·14 | 0·05 |
| Arsenic | not determined | 0·15 | 0·04 |
| Combined water | 3·90 | 3·00 | 1·96 |
| | 99·92 | 100·19 | 99·94 |
| Metallic manganese | 53·00 | 52·66 | 49·79 |
| Sulphur | 0·02 | 0·05 | 0·63 |
| Phosphorus | 0·05 | 0·06 | 0·02 |

**Titanic Iron.**—T. Koenig and O. von der Pforten * show that the formula of titanic iron is $FeTiO_3$, not $Ti_2O_3$, $F_2O_3$, as has hitherto been thought. Their experiments were made with menaccanite and titanic iron from Egersund and Snarum in Norway. Finely divided titanic iron turns dark blue when heated for several hours with concentrated sulphuric acid, and becomes covered with a white powder. The solution contains iron, but no titanium salt as stated by Glatzel.

* *Berichte der Deutschen Chemischen Gesellschaft*, vol. xxii. pp. 1485-1494.

**Recent Researches on Meteorites.**—E. Cohen * has analysed portions of the various constituents of the meteoric iron from S. Julião de Moreira, Minho, Portugal. After subtraction of the schreibersite, the nickel iron gave :—

| Iron. | Nickel. | Cobalt. | Copper. |
|---|---|---|---|
| 92·92 | 5·98 | 1·01 | 0·09 |

A similar composition is exhibited by several other hexahedral irons. The crust of the meteorite was found to consist of a mixture of nickel, iron, and schreibersite, with products of their decomposition. The iron sulphide was found to consist of 60·14 per cent. of troilite, and 37·58 per cent. of ferric oxide. The schreibersite gave, on analysis, results corresponding with the formula : $Fe_5(NiCo)P_2$. The analysis showed 1·31 per cent. of cobalt, an unusually large proportion.

S. Meunier † gives the results of the examination of a specimen forming part of a meteoric mass found in 1880 at Eagle Station, Kentucky. Ornaments made from portions of this meteorite have been found in a prehistoric burial mound in the vicinity. The meteorite has the structure of the ordinary syssiderites, and consists of a metallic mass, with numerous vacuoles filled with stony matter. The metallic mass has a concretionary structure, and contains the alloys tænite, $Fe_6Ni$, and kamacite, $Fe_{14}Ni$. It does not resemble the Atacama meteoric iron, since it contains augite associated with olivine. It has, in fact, the characteristics of the type of syssiderites distinguished in 1870 by the author by the term brahinite. The only specimen of this kind hitherto known is the meteoric mass found in 1822 at Brahin in Russia.

Daubrée ‡ describes a meteorite, 4½ lbs. in weight, that was found in the earth at Hamel-el-Requel, Algeria. It belongs to the holosiderite class, and externally resembles the Rio-Juncal meteorite. It is believed to have fallen in quaternery time.

J. E. Whitfield § has analysed a meteorite from the State of Durango, Mexico, and finds it to have the following percentage composition :—

| Fe. | Ni. | Co. | P. | S. | C. |
|---|---|---|---|---|---|
| 91·48 | 7·92 | 0·22 | 0·21 | 0·21 | 0·06 |

Troilite was observable in the meteorite, which was partially decomposed

* *Jahrbuch für Mineralogie*, 1889, No. 1, pp. 215–223.

† *Comptes Rendus de l'Académie des Sciences*, vol. cxviii. pp. 762–773.

‡ *Ibid.*, vol. cviii. pp. 930–931.

§ *American Journal of Science*, vol. xxxviii. p. 439.

**Pseudomorphs of Hæmatite after Iron Pyrites.**—Some perfectly preserved pseudomorphs of hæmatite after iron pyrites were found by Mr. R. H. Solly * in the calcareous red shale of Sattern Cove, Torquay. The crystals vary in size up to a large pea, and were found in a band about half a foot wide. The crystals have a hardness of 4 to 5, and a specific gravity of 4·5. A list of former occurrences of these pseudomorphs is given. On analysis the crystals show :—

| $Fe_2O_3$. | $FeS_2$. | $SiO_2$. | $Al_2O_3$. | $CaCO_3$. | $H_2O$. | Total. |
|---|---|---|---|---|---|---|
| 85·29 | 1·78 | 4·29 | 3·18 | 5·37 | 0·71 | 100·62 |

**Valuation of Iron Ores.**—Mr. S. B. Patterson † proposes the following scheme for the valuation of iron ores :—

1. *Metallic Iron*—
   a. Base, less than 40 per cent. per unit iron.
      40 to 44 per cent. inclusive add ¼ cent per unit.
      45 to 49 per cent. inclusive add ½ cent per unit.
      50 to 54 per cent. inclusive add ¾ cent per unit.
      55 to 60 per cent. inclusive add 1 cent per unit.
      60 to 64 per cent. inclusive add 1¼ cent per unit.
      65 per cent. and upwards add 1½ cent per unit.
   b. Taking unroasted magnetites as 100, calculate—
      Red hæmatites as 110.
      Brown hæmatites as 115.
2. *Phosphorus.*—Deduct for passing Bessemer limit 25 cents per ton, and 1 cent per ton additional for every 0·01 per cent.
3. *Sulphur.*—Deduct 1 cent for every 0·02 per cent.
4. *Silicates.*—Offset by bases in the following ratio :—
   Lime—1 per cent. offsets 1 per cent. of silica.
   Magnesia—1 per cent. offsets 1½ per cent. of silica.
   Then for excess of silica above bases, as above calculated, deduct 5 cents for every 1 per cent.

## II.—*IRON ORE MINING.*

**Reopening of the Tilly Foster Iron Ore Mine.**—The old method of working the Tilly Foster Mine, Putnam County, New York, was to sink on the ore body from the surface to the 165-foot level, where the vein is 100 feet wide. Ore pillars were left to support the hanging wall, which overhung nearly 50 feet, and finally caved in. Various attempts had been made, according to Mr. F. H. McDowell, ‡

* *The Mineralogical Magazine*, vol. viii. pp. 183-185.
† *The Engineering and Mining Journal*, vol. xlviii. p. 201.
‡ *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 758-767.

to recover the ore reserves and pillars by building brick arches, but without success. The method now adopted is to remove the whole of the country rock on the hanging wall in some parts as far down as the 300-foot level. Up to April this year, about 234,570 cubic yards had been removed, and of this 7211 cubic yards consisted of ore. At the narrow ends of the ore body, derricks are placed, and wire cables are stretched across the intervening space. Two of these are horizontal, and two are fixed to points about 100 feet below the surface. Sliding trolleys are carried by the ropes, and their positions are controlled by the winding-engines. The winding-ropes pass over pulleys on the trolleys. In order to save time, the bodies of the trucks are taken off their wheels and lowered into the pit for loading. Subsidiary cables are used for handling the stuff in the mine. By this method 1000 tons of rock are handled every ten hours.

**The Transport of Iron Ore in Spain.**—In a series of articles, F. Gisbert * describes the methods in use for the transport of minerals at the Sierra de Cartagena. Large quantities of iron ore are raised in the district and are exported by sea, the ports being Carthagena and Portman. From the mines to these ports the means of transport consists partly of aerial tramways, inclines and steam tramways, but from the smaller mines, or in rough country, the ore is chiefly sent in panniers on donkeys. The author describes in detail the aerial tramways at the Crisoleja and La Lucera mines. The first of these mines is the most important. The ore is limonite, containing about 50 per cent. of iron. It occurs in the form of a seam averaging about 26 feet in thickness. The pillar-and-stall mode of mining is adopted. The various parts of the wire ropeway connecting the mine with Port Portman are described by the aid of a number of diagrams. The Otto system is employed, the length of the rope being nearly 1¼ mile, the difference in elevation of the starting-point at the mine and the terminus at the port being 633 feet. The bearing rope is 1·18 inch in diameter, and the hauling rope 0·47 inch. The waggons are placed at intervals of 131 feet, each one holding from 550 to 660 lbs. The cost of transport of the ton of ore by this cable from the mine to the port was slightly less than twopence.

At the Lucera Mine the same deposit of ore is worked as at the Crisoleja Mine. The ore is taken to Port Portman by an Otto aerial tramway 1·40 mile in length, with a difference in level between the

* *Revista Minera*, vol. xl. pp. 233–235, 243–245, 249–252.

starting-point and terminus of 748 feet. The cables are of the same dimensions as those in use at the Crisoleja Mine. Each waggon carries 660 lbs.; they are placed at intervals of 131 feet. From 150 to 160 tons are carried daily, though as much as 180 tons has been reached. The normal velocity of the cable is about 526 feet a minute. Both lines are similar in their mode of erection and general construction, having been erected by the same engineer. The ore raised at the Lucera Mine is fairly pure, and contains about 52 per cent. of iron. The cost of mining at the Crisoleja Mine was 1s. 10½d. per ton of 22 cwt., and that of raising to the surface by an incline 1d.; this with the cable cost of 2d. makes a total of 2s. 1½d. At the Lucera Mine the total cost is 1s. 10½d., and at the El Humo Mine 1s. 5½d. The freight from Port Portman to the United Kingdom is about 13s. a ton.

At the El Humo Mine the ore is a limonite containing some 50 per cent. of iron; the annual output is about 100,000 tons. This mine is served by an incline 2412 feet in length, the difference in level between the top and bottom being 766 feet.

**Ventilation of a Prussian Iron Ore Mine.**—The installation of a new engine shaft at the Werner iron ore mine, at Bendorf, in the Wied mining district, rendered the old shaft available for ventilating purposes. In order to obtain a sufficient current of air in summer, the pipes of the old feed-water pump were allowed to remain in the shaft. These consist of cast iron flange-pipes, 3·94 inches in diameter and 233 feet long. They were connected at surface with the steam-pipe, and at the lower end introduced into a condenser. This arrangement was found to answer admirably, for the up-cast current, when the shaft was thoroughly dried, was quite sufficient for effecting the ventilation of the extensive mine workings. By regulating the steam-pressure, a ventilating current of varying intensity could be obtained. The consumption of coal was comparatively small; with uninterrupted working it did not exceed 12 tons a month.*

**Outbursts of Gas in Metalliferous Mines.**—Mr. Bennett H. Brough † has collected the records of cases in which outbursts of gas

* *Zeitschrift für das Berg-, Hütten- und Salinenwesen*, vol. xxxvii. p. 137.

† *Transactions of the North of England Institute of Mining and Mechanical Engineers*, vol. xxxviii. pp. 59-72.

have been observed in metalliferous mines, with a view to arriving at an explanation of the phenomena. Several cases are mentioned of explosions in iron mines, such as the explosions in the pisolitic iron ore mines of Alsace and in the Voulte iron mines. Accumulations of carbonic anhydride, of sulphuretted hydrogen, and of other gases are also referred to. Gas outbursts may be explained in several ways: by the decomposition of timber, in a similar manner to the decomposition of vegetable matter in marshes; by the production of hydrogen from water by the action of iron ores which are not completely oxidised; by the percolation of fire-damp from underlying shales and other gas-producing strata; by the decomposition of organic matter; by the production of sulphuretted hydrogen from pyrites and acid waters; and, lastly, by the production of carbonic anhydride from limestones and acid waters.

In the discussion, several instances were mentioned of explosive gases in iron ore mines in Cumberland, and in the Cleveland district.

**Tip Cradles.**—Details of an automatic tip cradle for mine waggons are given by Mr. H. S. Munroe.* The wheels of the truck run between the upper and lower arms of curved rocker irons, which are mounted on an axis below the centre of gravity of the truck when loaded, but above it when empty. The truck is thus easily turned over, emptied, and turned back again. Dimensions of the trucks used are fully given. The method of handling the ore at the Chapin mines, Lake Superior, is also described. An endless wire rope is used to haul the trucks in the mines. The trucks are taken up the shaft and run down inclined trestles to the ore pockets, near which the cradle is placed. The cradle is portable, and runs on wheels, so that it can easily be transferred from one place to another. The cradle itself consists of two iron rings held apart by angle irons, and free to revolve on rollers. The waggon fits in this cage, and is held by catches. The cradle is then run forward till a projection on the cage strikes an incline which sets it revolving, and so overturns the truck. The cage is righted by a man who rides on the platform.

* *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 564–570.

## III.—*METALLURGICAL PREPARATION.*

**Desulphurisation of Iron Ores.**—A series of experiments has been carried out by Mr. S. G. Valentine * in order to determine the conditions under which pyritiferous iron ores can be desulphurised. Most of the experiments consisted in heating pyrites to different temperatures, with and without access of air, and in similarly treating Cornwall ore containing 2·664 per cent. of sulphur. The author arrives at the following conclusions: Heat alone, without access of air, can only remove about half the sulphur. Atmospheric air is absolutely necessary for complete desulphurisation. Even at a low temperature, ore is properly desulphurised if air can gain access freely to the pyrites in it. Iron sulphate can be decomposed by heat equally well with or without air. In order that the residual sulphur in roasted ores may consist, as far as possible, of sulphates, the roasting must be done under free access of air. Fusion or sintering of the ore is likely to prevent desulphurisation of the ore, and does not allow of the formation of much sulphate; fusion should, therefore, never occur except after continued heating in air at a lower temperature. Ores cannot be properly desulphurised in the upper part of the blast furnace. An efficient roaster must allow easy control of heat, abundant access of air to the hot ore, and rapid removal of the products of combustion.

* *Transactions of the American Institute of Mining Engineers*, vol. xviii. (Advance proof).

# REFRACTORY MATERIALS.

**Fireclay Industry of Grossalmerode.**—According to Wiggert,* the fireclay deposits of Grossalmerode, Hesse, are of Tertiary age. The clay has the following percentage composition (I.) :—

| | I. | II. | III. | IV. |
|---|---|---|---|---|
| $Al_2O_3$ . . . . | 34·52 | 31·63 | 33·68 | 19 |
| $SiO_2$ chem. combined . | 43·38 | 34·44 | 49·90 | 70 |
| $SiO_2$ mech. mixed . . | 6·53 | 21·03 | | |
| MgO . . . . | 0·37 | 0·25 | 0·44 | ... |
| CaO . . . . | 0·76 | 0·15 | 0·48 | ... |
| $Fe_2O_3$ . . . . | 1·66 | 0·70 | 1·90 | 3 |
| $K_2O$ . . . . | 1·51 | 0·38 | 1·81 | ... |
| S . . . . . | 0·26 | 0·08 | 0·03 | ... |
| Loss on ignition . . | 11·04 | 11·40 | 11·63 | 7 |

For comparison, analyses are given of clay from Löthain near Meissen (II.), from Klingenberg on the Main (III.), and from Stourbridge (IV.).

The clay is worked in an economical manner by means of small shafts and adit levels. The production of fire-clay in 1885 amounted to 32,700 tons, and the industry afforded employment to 284 workmen.

**Calcining Magnesite.**—According to J. von Ehrenwerth,† magnesite must be exposed to an intense heat before it is used in the basic steel furnace, in order to drive off the carbonic anhydride and to prevent any further shrinkage. The contraction may amount to 50 per cent. When the material is burned in the ordinary lime kiln, the ash of the fuel is a disadvantage, and the operation of drawing is attended with great difficulty on account of the intense heat. The open-hearth furnace having being found well suited for magnesite in Styria, the author has designed a combination of a reverberatory furnace with a gas-fired kiln, drawings of which are given in the original memoir. The firing is effected by producer gas. The cost of a furnace of this description capable of producing 5 tons of dead-burnt magnesite daily amounts to £416 to £583, inclusive of gas-producer and stack.

* *Zeitschrift für das Berg-, Hütten- und Salinenwesen*, vol. xxxv. p. 336.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xxxvii. p. 102.

**Pennsylvanian Limestone.**—The following is an analysis of the limestone occurring near Bellefontaine, Pennsylvania: *—

| $CaCO_3$. | $MgCO_3$. | $FeCO_3+Al_2O_3$. | $SiO_2$. | Total. |
|---|---|---|---|---|
| 98·322 | 1·170 | 0·320 | 0·390 | 100·202 |

**Cement for Fire-Bricks.**—The Hüstener Company † in Westphalia proposes to employ phenolates as a cement for basic fire-bricks. By phenolates are understood the chemical combinations of hydrates of potassium, sodium, barium, and calcium, with the phenols resulting from the distillation of coal, peat, or wood. The tar from these materials is distilled, and the oil separated in the usual manner, giving phenols and carburetted hydrogen. The first products (carbolic acid, creosote) are mixed with the above-mentioned alkalies into a thin paste. The mass becomes warm by chemical action, and before cooling and solidifying the fire-resisting materials are to be added. In a few hours the mixture hardens like cement, and must at once be poured into the required moulds. The freer the cement is from neutral oils the harder and stronger are the blocks. . . .

Materials which when burnt have basic properties, such as marble, limestone, dolomite, after being burnt and reduced, can be mixed with phenol to a plastic mass. This mixture on cooling hardens with cement properties.

**Hungarian Magnesite and Dolomite.**—A. Gouvy ‡ states that the magnesite used at the Resicza basic open-hearth works is obtained from Nyustya in Upper Hungary. Its percentage composition is as follows:—

| $SiO_2$. | $Fe_2O_3$. | CaO. | MgO. | $CO_2$. | Total. |
|---|---|---|---|---|---|
| 2·75 | 4·30 | 2·50 | 42·58 | 47·87 | 100·00 |

The dolomite used at the same works is quarried near Armönis in Hungary, and the following analyses show its composition, both in its raw state and after burning:—

| Raw. | Per cent. | Burnt. | Per cent. |
|---|---|---|---|
| $SiO_2$ . . . . . | 1·54 | $SiO_2$ . . . . . | 0·70 |
| $Al_2O_3 + FeO$ . . . | 1·28 | $Al_2O_3$ . . . . . | 0·22 |
| $CaCO_3$ . . . . . | 52·50 | $Fe_2O_3$ . . . . . | 2·58 |
| $MgCO_3$ . . . . . | 44·10 | CaO . . . . . | 57·55 |
| | | MgO . . . . . | 37·82 |
| Total . . | 99·42 | $CO_2$ . . . . . | 0·93 |
| | | Total . . | 99·80 |

* *Iron Age*, vol. xliii. p. 357.
† *Dingler's polytechnisches Journal*, vol. cclxxii. p. 17.
‡ *Stahl und Eisen*, vol. ix. p. 398.

**Fireclay from Moravia.**—The clays and clay-slates of the Müglitz-Briesen district in Moravia are extremely refractory. Hecht * gives the following analyses of material from this district: 1. Clay from the Anton Mine; 2. Clay from the Ferdinand Mine; 3 and 4. Clay slates from the Anton Mine near Briesen; 5. Carboniferous sandstone from the Werner adit level:—

| | 1. | 2. | 3. | 4. | 5. |
|---|---|---|---|---|---|
| Silica | 45·61 | 44·87 | 43·48 | 46·13 | 73·42 |
| Titanic anhydride | ... | ... | ... | 0·16 | ... |
| Alumina | 39·31 | 39·76 | 39·43 | 36·24 | 19·60 |
| Ferric oxide | 1·13 | 1·14 | 1·61 | 1·26 | 0·55 |
| Lime | 0·37 | 0·76 | 0·22 | 0·60 | ... |
| Magnesia | trace | trace | trace | 0·12 | trace |
| Potash | 0·66 | 0·67 | 0·34 | 0·85 | 0·21 |
| Loss on ignition | 13·25 | 12·95 | 15·26 | 14·68 | 6·66 |
| Totals | 100·33 | 100·15 | 100·34 | 100·04 | 100·44 |

The sandstone (No. 5) is a good fire-resisting material. When submitted to a fire-resistance test in a Deville furnace it was found to have a melting-point lying between Nos. 33 and 34 of the Seger scale.

Both the slates (Nos. 3 and 4) are extremely hard, and of fine grain. They withstand elevated temperatures extremely well, being almost as good fire-resisting materials as the best Zettlitz china clay—they are, in fact, almost infusible.

**French Fireclays.**—The following are analyses (A) of the Breteuil kaolin, and (B) of a brick made from the fireclay occurring at Forges les Eaux, exhibited at the Paris Exhibition:—

| | $H_2O$. | $SiO_2$. | $Al_2O_3$. | $Fe_2O_3$. | CaO. | MgO. | $K_2O$. | $Na_2O$. | Totals. |
|---|---|---|---|---|---|---|---|---|---|
| A. | 9·30 | 41·38 | 47·80 | trace | 0·84 | ... | 0·20 | 0·56 | 100·08 |
| B. | 0·60 | 76·99 | 19·67 | 0·84 | 1·50 | 0·40 | ... | ... | 100·00 |

The firebrick is stated to be of exceptionally good quality.

* *Centralblatt für Glasindustrie und Keramik* (Vienna), vol. iv. p. 212.

# FUEL.

## CONTENTS.



## I.—*CALORIFIC VALUE.*

**Calorific Power of Carbon.**—Berthelot and Petit * treated finely pulverised wood charcoal with boiling hydrochloric and hydrofluoric acids successively. It was then heated to redness in a current of chlorine, and finally heated in a Perrot furnace. Six determinations of the calorific power were made in the calorimetric bomb with oxygen under a pressure of 25 atmospheres. The charcoal contained 99·34 per cent. of carbon and 0·66 per cent. of ash.

Similar determinations were made with graphite and with diamond. The graphite was purified by treating with hydrochloric acid, washing, drying, and heating to redness for a short time in presence of air. In order to burn the graphite it was mixed with one-third to one-fifth its weight of naphthalene, whose calorific power is accurately known. Powdered Cape diamonds, containing 0·12 per cent. of ash, were mixed with 11 to 16 per cent. of their weight of naphthalene. Other determinations were made with bort. These gave practically the same results. The calorific powers were found to be as follows:—

| | Calories. |
|---|---|
| Charcoal . . . . . . . . . . | 8137·4 |
| Graphite . . . . . . . . . . | 7901·2 |
| Diamond . . . . . . . . . . | 7859·0 |

* *Comptes Rendus de l'Académie des Sciences*, vol. cviii. pp. 1144-1148.

**Determination of the Calorific Power of Fuel.**—Dr. W. Thompson * has made several slight modifications in Mr. L. Thompson's calorimeter, and gives complete analyses of twelve varieties of coal, with the calorific power as found by experiment and by calculation. The author has previously described the apparatus.†

## II.—*COAL.*

**Formation of Coal.**—Some of the modes of formation of coal are described by Mr. J. G. Goodchild,‡ and in some points he agrees with the views expressed by Mr. W. S. Gresley.§ The generally received theory that the coal grew on the spot involves too many contradictions. It is generally agreed that the vegetable constituents vary within wide limits. Tree trunks form but a small portion of the deposit; part is formed of the harder parts of vegetation in a fragmentary condition, with detached portions of the cellular and vascular tissues of the plants; fronds and leaves are perhaps more plentiful, but the greater part consists of finely divided vegetable tissue, with spores, spore cases, and bodies of that general nature. The relative proportions differ considerably in various coals, but the constitution of a seam remains tolerably uniform over large areas. Coal is an aggregation of laminæ, each of which possesses characteristics of its own, so that they can often be identified over large areas. Even when the coal changes into carbonaceous shale, the constituents of the laminæ above and below remain fairly constant. As a general rule the coal passes by imperceptible degrees into argillaceous matter, but only rarely into sandstone. Sedimentary deposits nearly everywhere contain coal, which seems to occur under nearly the same conditions.

In the Carboniferous rocks, there occur shales, fireclays, and sandstones of different degrees of coarseness. If tree trunks are found they are generally in the sandstones, and lay root downwards like snags in present delta deposits. The shales and clays rarely contain trees, but fronds and leaves occur in plenty, and more rarely twigs. The fireclays, which have been regarded as the old soils, do not invariably contain roots or stigmaria, which sometimes appear in sandstone.

* *The Journal of the Society of Chemical Industry*, vol. viii. pp. 525–528.
† *Journal of the Iron and Steel Institute*, No. II. 1886, p. 859.
‡ Paper read before the Royal Physical Society of Edinburgh.
§ *Journal of the Iron and Steel Institute*, 1887, No. II. p. 238.

Coal, therefore, seems to possess all the characteristics of a stratified deposit, and resembles those strata that have accumulated in nearly still water. The persistence of the laminæ, and the fact that fireclay and coal are not always associated, seem to prove this.

The formation of coal implies a collection of vegetable matter under suitable conditions, and the deposit may be collected in several ways, as, for example, by the burial of peat or lagoon vegetation in inland or marine areas; by the accumulation of marine vegetation; or by the slow accumulation in quiet water of vegetable matter floated seawards from riparian forests. In considering this latter cause, the author showed that there is always much organic matter, partly animal, partly vegetable, brought down into the estuaries of rivers. Its origin might be terrestrial, fluviatile, or estuarine. Vegetable matter, as a rule, floats till it is water-logged. The coarser and heavier matter naturally sinks first, but the water-logged spores and vascular tissue of the plants are so light that they would be carried for great distances, farther in fact than is generally believed. Varying specific gravity and size would cause a fine assortment of the particles, which would be deposited each in its own place as long as the conditions remained unchanged, so that the coal might be deposited quite unmixed with mineral matter. A further sorting out would depend on the relative resistance to maceration. As soon as the strata were upheaved and the water shallowed, the coarser silts and sands would be deposited to cover up this submarine peat, and still greater elevation might lead to the formation of limestones.

**Formation of Lignite.**—Baron von Fritsch, in a lengthy paper read at the recent German Mining Congress at Halle, discussed the origin and mode of formation of lignite. He shows that at the time the lignite of Germany was formed the vegetation was more or less tropical in its nature, and that the probability is that by gradual inundation the forests were covered by the sea.

**Microstructure of Peat.**—A. Jentzsch* has investigated the microstructure of two varieties of peat from East Prussia. These are locally known as *Martörv* and *Lebertorf*. The former has a laminated structure, whilst the latter, when moist, consists of a gelatinous, uniform mass, and when dry, a hard compact material of a greyish-brown colour and a jet-like character. The microscopic investigation showed that the

* *Jahrbuch für Mineralogie*, 1889, vol. ii. p. 167.

*Martörv* has been formed chiefly of the leaves of grasses, and contains grains of quartz. The *Lebertorf*, which was first discovered in a bed 5 feet in thickness, under 9 feet of lowland peat, at Purpesseln, and subsequently in several of the peat bogs of East and West Prussia, and of Mecklenburg, was found under the microscope to consist of a granular mass, with numerous more or less distinct plant remains. Amongst these predominate pollen grains of *Pinus silvestris* and *Corylus*, and remains of Algæ. Besides these, there are remains of insects, shells of *Valvata piscinalis*, and occasionally diatoms. It is believed that cannel and Boghead coal have been formed in a similar manner.

**The Coalfields of France.**—Considered geographically there are three important coal districts in France. These are: (1) The Valenciennes district in the Departments of Nord and Pas de Calais, adjoining the Belgian coalfields; (2) the district comprising St. Etienne, Creuzot, Aubin, and Commentry, and which includes several small distinct coalfields; and (3) the Alais district. Altogether the coalfields cover about 2100 square miles. In 1887, 321 coal-mines were at work, giving employment to 99,386 workpeople, of whom 70,674 were employed underground. The average annual wage was £42. The following table shows the relative commercial position of the several districts :—

| District. | Production in 1887. | Value per Ton. |
|---|---|---|
| | Tons. | Francs. |
| Valenciennes . . . . | 10,373,000 | 9·82 |
| St. Etienne . . . . | 2,785,000 | 13·99 |
| Alais . . . . . | 1,705,000 | 12·36 |
| Creuzot and Blanzy . . . | 1,111,000 | 13·48 |
| Commentry . . . . | 730,000 | 11·95 |
| Aubin . . . . . | 641,000 | 9·80 |

The great variations in the price obtained for the coal is mainly due to the relative quality. More than 12 per cent. of the total quantity of coal raised was produced by the Anzin Company. This Company was founded in 1756, the production of the Anzin mines being at that date about 100,000 tons, coal-mining having been commenced at Anzin in 1734. In 1856 the annual output had reached 920,000 tons, and in 1888 as much as 2,595,000 tons.

**Coal in the Asturias.**—The coal output of the Asturias, Spain, for 1888, was 600,000 tons, as against 450,000 tons in 1887. Mr. J. H.

Collins * states that workable coal measures are confined to an area of 150 square miles. The country is mountainous, and the seams are very much inclined, or even vertical. Generally, workings are carried on through adits. The larger beds are 6 to 12 feet thick, those of 3 or 4 feet are preferred. In one case a seam of 15 inches is worked at a profit. The walls are usually strong, and but little timber is required. Each getter obtains from 20 to 25 cwt., and earns 1s. 7d. to 2s. per day. The coal is anthracitic, and has good coking qualities. It is screened over bars 1 inch apart; the fine portion is washed and coked in heaps or ovens, and the lump coal is exported. A yield of 65 to 70 per cent. is obtained by coking in ovens, the more primitive method yielding 50 to 65 per cent.

**Coal in British Columbia.**—Mr. G. M. Dawson, in a Report to the Director of the Geological Survey of Canada, states that Dr. W. F. Tolmie first published an account of the discovery of coal in British Columbia in 1835, specimens having been brought to him by Indians from the north-east coast of Vancouver's Island. Development work on a considerable scale was begun at Nanaimo in 1852, and before the close of the following year 2000 tons of coal had been shipped. In 1871 several hundred tons of anthracite were shipped from the Queen Charlotte Islands; but the mining operations were afterwards discontinued. The total production of coal from all the mines of British Columbia has steadily increased from 81,547 tons (of 2000 lbs.) in 1874 to 489,301 tons in 1888.

The series of mineral fuels found in British Columbia ranges from lignites, with a distinct woody structure, to anthracites, which compare favourably with those of Pennsylvania or Wales. The beds containing the anthracite are almost vertical, and it is evidently on account of the disturbance and local alteration which it has undergone that the coal has passed into the condition of anthracite. The best seam found has a maximum thickness of a little over 6 feet, whilst a second adjacent outcrop showed a thickness of 2 feet 5 inches, and other less important outcrops also occur. It is probable that these various outcrops represent a single seam repeated by folding.

The Comox and Nanaimo coalfields are the most important in the province, and it is from the Nanaimo field that most of the coal has hitherto been raised. Its area is estimated at about 200 square miles. Three collieries are at present in operation—the Nanaimo, Wellington,

* *The Colliery Guardian*, vol. lviii. p. 240.

and East Wellington. The works of the two former are on a very extensive scale, embracing numerous shafts and inclines. They are provided with good machinery, railways, and wharves. In the Nanaimo colliery the principal workings are upon a seam which averages from 6 to 10 feet in thickness. A second seam, overlying this one, and separated from it by 140 feet of sandstone, is 7 feet thick. The seam worked in the Wellington Colliery is about 9 feet in thickness. The coal, which is a rather dry steam coal, does not afford a strong coke. The Nanaimo coal, on the other hand, yields a good coke, and also gives a large quantity of illuminating gas.

The Cretaceous rocks constituting the Comox and Nanaimo coalfields border the south-western side of the Strait of Georgia, and form a belt of comparatively low rolling or hilly country, between the mountainous region of the interior of Vancouver Island and the coast. The quality of the Comox coals is equal, if not superior, to that of the coals found in the Nanaimo field.

**Indian Coalfields.**—Six illustrations are given in the *Indian Engineer* * of borings in the Palamow or Daltongunge coalfield, showing the coal in some places to be as much as 11 feet thick. The estimated carriage by a proposed railway is 150,000 tons yearly. An assay of the Pandua coal by Mr. Tween shows—

| Fixed Carbon. | Volatile Matter. | Ash. |
|---|---|---|
| 64·4 | 22·2 | 13·4 |

**Brazilian Coal.**—Brazilian coal from Arroio dos Ratos has been examined by Mr. J. Pattinson † with the following results. On submitting the coal to distillation in a coal-testing apparatus, 8000 cubic feet of gas was obtained per ton of coal. The gas had an illuminating power equal to 13·8 standard sperm candles. The following percentages of coke and volatile matters were yielded:—Coke, 58·8 per cent.; volatile matters, 41·2 per cent. The coal swelled up but very slightly on being heated in a closed retort, and formed a slightly coherent coke. A complete ultimate analysis of the coal was made with the following results:—

| Carbon. | Hydrogen. | Oxygen. | Nitrogen. | Sulphur. | Ash. | Water. |
|---|---|---|---|---|---|---|
| 53·84 | 3·91 | 8·23 | 0·59 | 3·65 | 17·01 | 12·77 |

The calorific power of the coal was determined in a Thompson calori-

* Vol. vii. pp. 113–116.

† *The Weekly Bulletin*, Aug. 17, 1889, p. 107.

meter. This indicated that 1 lb. of the coal would evaporate 10·3 lbs. of water from 212° Fahr.

**Coal in New Caledonia.**—M. Porte * has recently presented a report on the occurrence and composition of the coal in New Caledonia. Particulars are given of the various situations in which coal has been found and worked. In the Mont D'Or district at the Bully colliery a bed of over 18 feet thick has been found, and numerous other seams are known to exist. Two kinds of coal occur, the one an anthracitic coal capable of yielding coke, the other a bituminous coal. With reference to the amount of coal, it is estimated that about one and a quarter million tons could be obtained yearly for the next ten years. Twenty assays are given from different localities, of which the following may be taken as typical :—

| | Volatile Matter and Water. | Fixed Carbon. | Ash. |
|---|---|---|---|
| Portes-de-Fer . . . . . | 17·50 | 77·00 | 5·50 |
| Moméa . . . . . . | 37·50 | 51·50 | 11·00 |
| Oua Poquereux . . . . | 27·00 | 64·00 | 9·00 |

The ash in one case rises as high as 26 per cent.

**Alabama Coalfields.**—A very full account is given by Mr. C. A. Ashburner † of the development of the Alabama coalfield. The total production in 1887 was 1,950,000 tons (of 2000 lbs.). By the latest estimate the coalfields cover 8660 square miles and comprise three divisions—the Warrior, Cahaba, and Coosa districts. In the Warrior field it is estimated that there are 108,394,000,000 tons of available coal in seams over 18 inches thick, of which there are 50 seams in the coal measures, which reach a thickness of 3000 feet near Tuscaloosa. The beds in this field are generally more level than in the others.

A table is given showing the number of mines worked by various companies, with their output, wages, &c., together with particulars of the working at each mine.

The following are representative assays of coal and coke produced by the various companies :—

* *Le Génie Civil*, vol. xv. pp. 450–451.

† *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 206–226.

| | Coal. | | | | | |
|---|---|---|---|---|---|---|
| Ash | 3·01 | 1·92 | 1·27 | 3·20 | 2·41 | 1·90 |
| Fixed carbon | 65·07 | 63·03 | 65·12 | 55·76 | 60·75 | 58·61 |
| Volatile matter | 30·74 | 33·83 | 32·24 | 41·04 | 34·12 | 37·73 |
| Sulphur | 1·20 | 1·20 | 0·56 | 1·01 | 0·48 | 1·95 |
| Water | 0·93 | 1·17 | ... | ... | 2·24 | ... |

| | Coal. | | Coke. | | | |
|---|---|---|---|---|---|---|
| Ash | 7·36 | 6·00 | 4·78 | 10·49 | 6·20 | 10·54 |
| Fixed carbon | 50·69 | 68·34 | 92·30 | 85·77 | 92·32 | 87·30 |
| Volatile matter | 41·12 | 22·15 | 1·60 | 3·04 | 0·40 | 0·80 |
| Sulphur | 0·42 | 1·85 | 1·12 | 0·54 | 0·82 | 1·19 |
| Water | 0·83 | 1·66 | 0·20 | 0·15 | 0·25 | 0·15 |

The mines which are at present in operation have a capacity of 6800 tons, other mines which are being opened will increase this total by 2900 tons daily. The average of coal owned by companies is 233,000 acres, the rest is still Government property.

In an article published in another journal,* it is stated that the Underwood seam, worked by the Cahaba Coal Mining Company, Alabama, is 6 feet thick, and lies in a basin about 2½ by 5 miles long, with a dip of 5 to 10 degrees. The following assay is given of the coke:—

| | Coke. |
|---|---|
| Moisture | ... |
| Volatile matter | 4·508 |
| Fixed carbon | 87·607 |
| Sulphur | 0·745 |
| Ash | 7·140 |
| | 100·000 |

**North-Western Colorado Coal Region.**—A coal region covers an area of about 150 miles square on the northern half of the Pacific slopes of Colorado. Mr. G. C. Hewett † describes the formations above the Carboniferous as being largely developed, while all below are but meagrely shown. The whole geological section is torn and distorted in every period, so that the Carboniferous strata are much crushed and twisted, and accordingly the coal is not likely to be of much value. The productive Cretaceous coal measures are 700 to 1200 feet thick, and contain two or three beds of coal. Farther above, in the Tertiary strata, are some oil shales.

The coal measures lie in two fields—one lies between the rivers Gunnison and Yampa, the other is an extension of the Green River

* *American Manufacturer*, vol. xlv., No. 6.

† *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 375-380.

field in Wyoming. When unchanged by flexure, the seams carry lignite, with 5 to 20 per cent. of water. In some parts the changes from anthracite to coking and non-coking coals are exceedingly rapid.

The author then proceeds to describe the general trend of the outcrop, and to indicate the position where good coal is found in more or less accessible positions. The floor and roof of the seams are generally composed of clay slate that slacks and crumbles on exposure. These facts, together with the dip of the seams, render mining a difficult operation.

**Coal in Gunnison County.**—After dealing with the iron ores of Gunnison County, Colorado, Professor R. Chauvenet * gives the following assays of coals and cokes from that locality :—

| | Coal | Coke. | Coal. | | |
|---|---|---|---|---|---|
| Water | 1·18 | ... | 1·58 | 0·90 | 9·29 |
| Volatile matter | 28·39 | 0·42 | 5·66 | 33·43 | 30·93 |
| Fixed carbon | 67·06 | 90·71 | 89·76 | 61·25 | 55·72 |
| Ash | 3·37 | 8·87 | 3·00 | 4·42 | 3·48 |
| Sulphur | ... | 0·37 | ... | ... | 0·58 |

**Coal in Kentucky.**—The coal in the Jellico district † appears to be an extension of that in the Elkhorn coalfield. It lies on a strong fireclay floor, and the roof is a heavy layer of sandstone, without apparent intervention of shale. At the bottom is 22 inches of coal, then 7 inches of clay-parting, and then 28 inches of coal. Two assays of the coke are given ; the first was coked for 48 hours.

| | | |
|---|---|---|
| Moisture | 0·20 | 1·50 |
| Volatile combustible matter | 1·35 | ... |
| Carbon in the coke | 95·20 | 93·30 |
| Sulphur | 1·23 | 0·382 |
| Ash | 3·25 | 5·20 |
| Specific gravity | 1·50 | ... |
| Percentage of cells by volume | 61·0 | ... |
| Weight lbs. per cubic foot | 55·87 | ... |

**Bernice Anthracite Basin.**—This basin is the westernmost and largest of the deposits in Sullivan and Wyoming Counties, Pennsylvania. The basin, which is described by Mr. C. R. Claghorn, ‡ is

* *Report of the State School of Mines, Golden, Colorado*, pp. 24–25.

† *American Manufacturer*, vol. xlv. No. 11.

‡ *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 606–616.

about 4 miles long and 1500 feet wide. The beds dip towards the centre, but contain many "rolls" and "sumps," which hold the water, and render mining difficult. There are two beds. The lowest is 10 to 20 inches thick, and is of no economic value. The other bed is 40 to 65 feet above the lower one, and consists of three splits, with thin dirt-partings near the edge of the basin, which thicken towards the centre of the deposit, so that the top splits are separated by 45 to 60 feet, and the lower ones by 15 to 25 feet. The bottom coal varies from 4½ to 5½ feet, the middle from 1 to 2 feet, and the top coal from 3 to 3½ feet.

The coal is anthracite, with a distinctly bituminous character when freshly mined. Several assays are given. The most recent shows:—Moisture, 1·81; volatile matter, 6·56; fixed carbon, 85·73; ash, 5·90 per cent.; the carbon ratio being 1 to 13·08. The ash never clinkers.

Mining operations are carried on by the State Line and Sullivan Railroad Company, at the western end only. The pillar-and-stall system is adopted, and the coal is hauled by a small locomotive. The frequency of "sumps" renders a regular disposition of the workings impossible. The basin is drained by a shaft, 80 feet deep, sunk to the centre and deepest part. Special efforts are made to keep the workings of the top in advance of those of the lower coal. The coal is dumped over screens on to a circular cast iron revolving table, where it is broken with a kind of stamp-head with steel teeth.

The total production from 1871 to 1886 was 1,197,236 tons; in 1887, 96,000 tons were mined, and 105,107 tons in 1888.

The lowest seam gave on assay:—Moisture, 1·43; volatile matter, 10·17; fixed carbon, 85·72; ash, 2·68; sulphur, 0·12; carbon ratio, 1 to 8·4. Other analyses give a carbon ratio of 1 to 4·4, or 1 to 4·6. Part of this bed is therefore semi-anthracitic, and changes to bituminous within one and a half miles. This is therefore an instance of a bituminous bed occurring below a true anthracite coal, and seriously affects the general theory that anthracite is formed by the action of heat on a bituminous coal.

**Coal in West Virginia.**—Mr. W. N. Page * describes the coal and iron formations on the Glenmore Iron Estate, Greenbrier County, West Virginia. Details of the topography, geology, and iron ores are given. Thirteen workable coal measures have been proved, aggregating about 70 feet of coal. The limestone and iron ore, containing

* *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 115-124.

61 per cent. of metallic iron, are both of good quality. On assay the coal shows :—

| Carbon. | Sulphur. | Volatile Matter. | Ash. |
|---|---|---|---|
| 82·16 | 0·90 | 5·05 | 11·81 |

**The Age of the Tipton Run Coal, Pennsylvania.**—The Tipton Run coalfield, Blair County, lies along the eastern base of the Alleghany Mountain, twelve to fifteen miles north-east from Altona, Pennsylvania. The deposit lies several hundred feet below the lower Coal Measures, and has generally been referred to the Lower Carboniferous sandstones. Mr. I. C. White * has, however, discovered that the enclosing shales and sandstones contain fossils of Coal Measure age. The character of the coal and of the beds on which it rests are similar to those found on the summits of the Alleghanies, a few miles distant. It would thus appear that the Tipton coal has been faulted downwards to its present position, or else brought there by a deep local syncline.

**Lignite Briquettes.**—In a paper read at the German Mining Congress at Halle, the uselessness of attempting to dry the lignite used in the manufacture of briquettes is pointed out by Vollert, experience having shown that the presence of from 15 to 20 per cent. of moisture in the briquette greatly increases its resistance to atmospheric action and to disintegration during transport. Great care has to be taken to prevent the collection of dust during the manufacture of the briquettes, owing to its liability to explode. The numerous arrangements which have been adopted to prevent danger from such explosions are referred to by Schröcker, who shows that, whilst in 1875 there were in North Germany only 29 briquette presses, consuming annually 250,000 tons of lignite, there are, at the present time, 186 such presses at work, each giving employment to 10 men, with an annual consumption of 2,250,000 tons of lignite, and a production of 1,250,000 tons of briquettes. Unfortunately, this manufacture of lignite into briquettes is accompanied by considerable danger, owing to the evolution of hydrogen and other gas, and to the explosive character of the dust produced in the manufacture. This dangerous deposition of dust takes place partly during the preliminary drying of the fuel, but more especially during the transport of the dried material to the press. In conclusion, the various mechanical arrangements which have been introduced to prevent such dust deposits are referred to.

* *American Manufacturer*, vol. xlv., No. 2.

## III.—*COKE.*

**A New Coke Oven.**—Messrs. Bernard and Seibel exhibited at the Paris Exhibition drawings of a modified form of the Seibel horizontal oven. The oven is intended more particularly for the treatment of badly coking coals. In this oven the coal begins to coke at the upper part of the coking chamber, the coking gradually proceeding from the top downwards. The temperature should be as high as possible. The oven resembles the Belgian type. The gases escape through openings in the roof, pass upwards to a combustion chamber, and then descend through a series of openings to two channels below the oven, pass thence below the bed of the adjoining oven, and finally escape to the stack through a channel common to the whole of the battery. Ovens of this type were erected at the Karwin collieries in Austria in 1887. Some of the ovens erected are 29 feet 6 inches in length, 5 feet 3 inches high, and 2 feet wide. Others have been built still higher, about 6 feet 6¾ inches.

**Coke Ovens at the Isbergues Steelworks, France.**—At these works there are 100 coke ovens of the Evence Coppée or Siebel-Bernard type.† These ovens are 29 feet 6 inches in length, 6 feet 7 inches in height, and 2 feet in width. The coal coked is bituminous coal from the Pas-de-Calais. The charge is about 7 tons, and the yield from 5·2 to 5·3 tons of coke, containing 12 per cent. of ash, the volatile products of the coal being about 23 per cent.

**The Bauer-Ruederer Coke Oven.**—Messrs. Bauer and Ruederer of Munich publish † a sketch plan and section of a 24-chambered coke oven battery. This battery is circular, the chambers being arranged radially around a central stack. The chambers are vertical ones, the charging being effected at the top in the usual manner. Each chamber holds 2 tons of coal, and the duration of the coking is from eighteen to twenty-four hours. The formation of the chambers admits of a rapid withdrawal of the coke, the time required varying from six to ten minutes. The coke falls on to a rotating band, on which it is cooled, separated from smalls, and automatically discharged into waggons. The combustion spaces are easily repaired. The various coking chambers are independent of one another, and are filled and discharged at

* *L'Echo des Mines*, vol. xiv. No. 41, p. 4.
† *Stahl und Eisen*, vol. ix. p. 788.

will without interference with the other chambers of the battery. The ovens may be constructed in such a manner as to admit of the collection of the by-products, but in the drawing published, this is not the case, the products of distillation being burnt in combustion spaces arranged around the coking chamber. The back wall and bed of the oven form a parabola, the intention being to facilitate in this way the removal of the coke. As many as forty ovens may be arranged in one battery.

**Coppée Coke Ovens at Maesteg.**—A block of sixty ovens on the Coppée system and a coal washing plant are being erected at Maesteg, Wales, by the North's Navigation Collieries Company. The small coal is tipped from the trunks into a pit and raised 60 feet by an elevator into a revolving screen. Coal above $\frac{3}{4}$-inch size is washed separately and sold. Smaller coal is further sized in a revolving screen and sent to separate felspar washers. The coal settles in a basin, whence it is carried by an Archimedean screw and elevators to storing bunkers, and then by trollies to the ovens. The charge for each oven is three tons, which is levelled by rakes through openings in closed doors. Coking occupies twenty-four hours, so that seven charges a week can be worked off. Charging and discharging take ten minutes. One engine is employed to drive all the machinery, and the whole of the buildings are lighted by electricity.*

**The Collection of the By-Products from Coke Ovens.**—The progress which has been made of recent years in the collection of the by-products from coke ovens may be noted by observing the number of improved ovens that have been erected. Of one type alone, the Hoffmann-Otto, as many as 665 have been built at various places, and others are now in course of construction. The methods of condensation adopted in the various systems of construction differ greatly. In the water-cooled condensers, heavy and light tarry matter are sometimes found in admixture. To prevent this, it has been endeavoured to collect the greater part of the heavy tar, together with any particles of dust that may have been carried forward, by the use of air-coolers placed before the water-coolers. In most cases the gas, freed from the greater part of the condensible products of dry distillation, is passed in finely divided currents through a layer of water, which induces the separation of a further portion of tarry matter. In the systems at first

* *Iron and Coal Trades Review*, vol. xxxviii. p. 780.

adopted, the exhaust was situated behind the coolers and the washers, now, on the other hand, it is placed between them. Practice has shown that only from 11 to 14 per cent. of the total nitrogen present in the coal is collected in the form of ammonia. Various methods have therefore been proposed for the purpose of increasing this percentage. Past experience has shown that with increasing temperature the percentage of ammonia also increases. The belief that ammonia dissociates at a temperature of 780° C., is therefore not confirmed by the results of practical work. Other experiments have shown that the percentage of ammonia increases perceptibly if hydrogen is passed through the coal undergoing dry distillation. Lime, too, has been found to increase the yield of ammonia, but it deteriorates greatly the quality of the coke produced, the strength being considerably diminished. This is probably due to the action of the water on the lime when the red-hot coke is cooled after drawing.

Efforts have also been made to increase the yield of tar by endeavouring to prevent the dissociation of tarry matter in the oven by the use of cooling arrangements. Good coke, however, can only be produced at a high temperature, so that the use of such cooling arrangements on the roof or sides of the oven tends to deteriorate the quality of the coke produced.

The ammonia collected in the condensers is converted into sulphate, the ammonia being first distilled off from the condenser water, lime being added to decompose any ammonium compounds present. A number of kinds of apparatus have been introduced for use in this process. The ammonia driven off is passed into sulphuric acid, which is diluted down to about 38° or 40° B. The sulphate is removed from time to time and fresh acid added.*

Some experiments † have been made with coke ovens arranged for the collection of the by-products at the Calumet Steelworks, United States. The ovens were erected by the National Coke and Fuel Company of Chicago, and the experiments showed that for every ton of coal coked there were obtained 15,000 cubic feet of fuel-gas, from 3 to 5 gallons of coal oil, and ammonia in quantity equivalent to about 3 lbs of the sulphate. In the beehive ovens, in which these experiments were made, the downward process was adopted, as in Jameson's ovens, the volatile matters being withdrawn through a hollow floor.

* *Stahl und Eisen*, vol. ix. pp. 482-485.
† *Iron Age*, vol. xliii. p. 692.

**Dust from Coke Oven Gases.**—B. Platz * has observed the formation of a white dust in the tubes of a boiler heated with the waste gases from coke ovens in which Westphalian coal was being coked. On analysis it was found to have the following percentage composition :—

| $ZnSO_4$. | $PbSO_4$. | $K_2SO_4$. | $Na_2SO_4$. | $Fe_2(SO_4)_3$. | Residue. | Total. |
|---|---|---|---|---|---|---|
| 63·01 | 11·23 | 4·82 | 5·54 | 12·22 | 1·62 | 98·44 |

A similar dust, but of a yellow colour, contained :—

| ZnO. | $PbSO_4$. | CaO. | MgO. | $Al_2O_3$. | $Fe_2O_3$. | $SiO_2$. | Total. |
|---|---|---|---|---|---|---|---|
| 58·43 | 4·24 | 1·12 | 0·75 | 8·40 | 5·49 | 17·78 | 96·21 |

The formation of this dust is due to the fact that nearly every coking coal of the Westphalian District contains galena and zinc blende, the latter frequently in considerable quantities.

**Coke-making Boiler.**—Kingsford's coke-making boiler is described and illustrated by four sections in *The Engineer.*† The boilers are made on the elephant principle, and are placed over the coke ovens so as to be heated by the waste gases therefrom. The coke is stated to be good, and is made at a profit.

**Arkansas Coke.**—The coals of Arkansas ‡ are of very varying capabilities, and in general do not appear to make good coke. Jenny Lind coal was tested in a rectangular oven taking a charge of 400 to 800 lbs., but the product was of poor quality, though it is freer from sulphur than many others. Crucible tests have been made of several kinds of coal, and the results are given. Working tests have been made in beehive ovens with Huntingdon and Hackett City coals, and in heaps at Greenwood. Either the coal will not coke, or it produces a product similar to gas-coke. As a rule, all the coal in Arkansas contains a low percentage of volatile matter, and will probably behave like the Jenny Lind coal.

**Cost of Coke-making at Connellsville.**—In connection with the Connellsville coke strike, the following details § of the cost of coke-making at two good works in this district are given :—

* *Stahl und Eisen*, vol. ix. p. 755.
† Vol. lxviii. p. 187.
‡ *Annual Report of the Geological Survey of Arkansas*, vol. iii. ; *The Age of Steel*, vol. lxvi. No. 13.
§ *American Manufacturer*, vol. xlv. No. 6.

| | s. d. | s. d. |
|---|---|---|
| Cost of coal . . . . . . | 2 9·75 | 3 0·6 |
| Coking . . . . . . | 1 6·25 | 1 4·05 |
| Royalty . . . . . . | 0 6·05 | 0 6·05 |
| Cost per ton . . . | 4 10·05 | 4 10·7 |

In the latter case labour costs 13·75 pence; supplies, 0·4 penny; and repairs, 1·9 penny per ton.

## IV.—*LIQUID FUEL.*

**Oil in New Zealand.**—The New Zealand Government has recently issued a report dealing with the Taranaki district. The oil comes to the surface in many places near New Plymouth. Mr. Gordon * reports that oil exists over a large area, and that it is only a question of boring to the requisite depth. The oil-bearing districts could easily supply the fuel for the iron sand beaches of New Zealand.

**Burmese Oil Fields.**—Dr. F. Noetling † has reported on the oil fields of Burma. The Yenangyaung district is conveniently divided into the Twingoung and the Beme districts, situated in lat. 29° 21′ N., long. 94° 56′ E. The country forms an elevated plateau intersected by ravines. The strata belong to the Upper Tertiary formation, and consist of a soft sandstone impregnated with oil. At present the deepest borehole is only 400 feet, proving the oil-bearing strata to have a thickness of 200 feet, but the amount of oil increases largely with the depth. No high gas-pressure has as yet been found. The strata form an anticlinal, with a strike N. 40° E., and a maximum dip of 30° to the S.W. and N.E., so that most of the wells driven by the natives have been sunk on the top of the anticline.

In the Twingoung field there are 209 productive wells, producing 12,000 viss ‡ daily, but the wells are very shallow, the deepest being only 310 feet. The Burmese method of getting the oil is to sink a shaft about 4½ feet square, a matter of great difficulty, as the miners cannot breathe the explosive air, and only use most inefficient tools. A well, however, yields some 23 per cent. interest. There are 72 productive wells in the Beme district, with a daily production of 14,000 to 20,000 viss, and the deepest well is only 270 feet in depth.

* *Engineering*, vol. xlviii. p. 316.
† *Records of the Geological Survey of India*, vol. xxii. pp. 75–136.
‡ 1 viss = 3·65 lbs.

**Beluchistan Oil Fields.**—Mr. R. A. Townsend * reports on the latest advances made with the borings for oil in Beluchistan. A boring has been put down at Khirta, in the Bolan Pass. Eighteen feet of gravel cemented with oil were passed through, then 180 feet, chiefly of olive eocene shales, at which point warm sulphur springs with thick oil were struck. By the end of last March the depth was 360 feet, and the water had been kept out by a double lining.

**Comparison of Fuel Oil and Coal.**—An analysis of Lackawanna coal † shows—

| Fixed Carbon. | Volatile Matter. | Water. | Sulphur. | Ash. |
|---|---|---|---|---|
| 83·27 | 4·38 | 3·42 | 0·7 | 8·2 |

and the calorific power is 9939 thermal units, as against 11,555 for a sample of fuel oil. The ratio is thus 1 to 1·16, and one gross ton of coal equals 6·7 barrels of oil, each holding 42 gallons. To the cost of the coal must be added the labour for handling its greater bulk and its ashes, and in one case this was 21 per cent. of the cost of the coal. The ratio of coal to oil then becomes 1·37 to 1, so that for these particular qualities the prices must be above or below that ratio to give an economy for either. The question is further complicated by that of storage room, &c.

**Oil as Fuel.**—Trials have been made at the Pennsylvania Steel Works with oil as fuel for heating and open-hearth furnaces, and the results are given by Mr. E. C. Felton.‡ The amounts of oil stated include that used for keeping the furnace hot over Sundays.

Hot 14-inch ingots, six to a charge, were heated in Siemens heating furnaces, with a consumption of 6½ gallons per ton during six weeks. For the 30-ton open-hearth furnace, charged with cold scrap and pig, 48 gallons were used per ton of ingots during a month's trial. In both cases the oil was partly refined, and in the latter case the gas was carried a distance of 300 feet from the producer to the furnace. For six months, six Siemens heating furnaces have used 6 gallons of Lima oil per ton of ingots. Under favourable circumstances, this quantity has fallen to 4 or 4½ gallons. Lima oil was also used for heating a 30-ton open-hearth furnace. The average of a six weeks' run gave a result of 54 gallons per ton, and the record of the first

* *The Indian Engineer*, vol. vii. pp. 206–207.

† *American Manufacturer*, vol. xlv. No. 6.

‡ *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 809–810.

week was 46·7 gallons. It was found that the loss is somewhat greater than with coal gas, and some trouble was experienced from the clogging of the checquer-work by fine iron oxide. In a 5-ton open-hearth furnace 50 to 55 gallons were used per ton.

Mr. E. C. Potter * gives the results of using oil at the South Chicago Works in place of coal for raising steam. For operating fourteen tubular boilers, 16 feet long by 5 feet diameter, twenty-five men were required when coal was used and only six men when oil was substituted. With an ingot output of 6403 tons, 2731 barrels of oil were used as against 848 tons of coal. The saving in wages was £7, 18s. 4d. per day. Taking the oil at 2s. 6d. per barrel and coal at 8s. 11½d. per ton, the cost of oil and coal were respectively 8s. 0½d. and 8s. 11½d. per ton, giving a net saving of 11d. per ton.

For a similar battery of twenty-six boilers the rail output was 5208 tons, with a consumption of 5987 barrels of oil instead of 1805 tons of coal. In this case the costs were 8s. 3d. and 8s. 11½d. respectively. The efficiency of the boilers was somewhat increased and the necessary repairs diminished.

Mr. G. H. Billings † gives the results with the earlier form of the Archer apparatus applied to a puddling furnace. To heat the furnace 3518 lbs. were required, and 8437 lbs. more were burnt to give 13,340 lbs. of puddled blooms. At 2·44 pence per gallon the oil cost £2, 5s. 5½d. per ton of blooms, and the cost with coal at £1, 0s. 4d. per ton, using 1·5 ton of fuel per ton, was £1, 10s. 5½d. A run of six days used 6602 gallons for a production of 65,595 lbs. of blooms, and showed a saving in favour of coal of 18s. 9d. per ton.

For generating steam, 4156 lbs. of oil evaporated 27,600 lbs. of water per day. Assuming that one pound of coal evaporates nine pounds of water, with prices as above, the costs were £15, 19s. 11d. for oil, and £3, 6s. 6d. for coal, daily.

A test ‡ has recently been made of oil fuel in a puddling furnace. The oil is supplied through a perforated pipe on to a heap of fire-clay balls supported on the grate. The pipe may be cleared if necessary by a revolving screw inside. Air is supplied by the natural draught of the furnace. In the experiment three-quarters of a barrel of oil was burnt in 1½ hour for a heat of 500 lbs., but probably less oil would be required if the apparatus were less crude.

* *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 807–808.
† *Ibid.*, vol. xvii. pp. 808–809.
‡ *American Manufacturer*, vol. xlv. No. 7.

**Caucasian Petroleum Industry.**—In order to contradict a rumour which has recently been circulated * of the exhaustion of the Baku oil wells, Professor D. Mendeléeff † has forwarded a long communication, dealing with the present and future prospects of the district. According to the author's own experience in 1886, and the reports of Professor Meller, Torokin, and others in 1887, there has not been a single sign of exhaustion. The precipitate conclusion as to exhaustion has been made from wells near the village, especially near Balakhani in the upper layers. Exploration near Romany and in the Beybat district shows the presence of large quantities of oil.

The pumping of the naphtha depends on the demand, which is less in the winter, and many of the smaller wells are not worked unless the price rises. The highest production of the district has not yet been reached, and will not be till the pipe line to the Black Sea is constructed. Even if this particular district were exhausted, there are still large fields open for exploitation and exploration. These districts have not been touched as yet, owing to the difficulties of transport. In addition to this, the Government controls the industry to such an extent that it prevents local owners selling or leaving their land for exploitation, so that the only district that is worked is the two square miles of land at Baku. Here there are about 200 wells, and statistics show an increase in the average yield. The author also refers to his theory of continuous production as affecting the question, and deals with the relative production of American districts.

**Asphalt and Petroleum.**—The various hydrocarbons are divided by Mr. F. V. Greene ‡ into four classes. The first class includes those in a free state as liquids, such as petroleum; the viscous, as found in tar springs and gas-tar, and the solid glance pitch. Secondly, those mixed with earthy matter, such as the asphalt from Trinidad. Thirdly and fourthly, those combined with silica and with lime respectively. The author then proceeds to describe the various sources and methods of treatment of bituminous sandstones and limestones, and also gives a description of the pitch lake at Trinidad. The crude asphalt from the latter place contains:—

* Report by the Consul-General at Odessa.

† *The Journal of the Society of Chemical Industry*, vol. viii. pp. 753–757.

‡ *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 355–375.

| Bitumen. | Earthy Matter. | Vegetable Matter. | Water. |
|---|---|---|---|
| 39·83 | 33·99 | 9·31 | 16·87 |

Mr. H. Wurtz * ascribes the origin of asphalts mainly to the polymerisation of certain constituents in rock oils under the influence of air, light, heat, or by the presence of saline and other matters. The theory of oxidation and inspissation is rejected. The author gives an account of several polymers, and the way in which they can be produced in support of his view.

## V.—*NATURAL GAS.*

**Coal and Natural Gas.**—The future of coal and natural gas is discussed by Dr. J. S. Newberry.† All oil and gas wells are situated in sedimentary rocks, and are in close relations with carbonaceous deposits. The oil and gas wells of Burkesville, Kentucky, Lima, Ohio, Enneskillen, Collingwood, and Canada are supplied from the bituminous shales and limestones of the Lower Silurian age. The wells of West Virginia, New York, and Pennsylvania are supplied from the bituminous shales belonging to the Devonian system. The oil wells of Mecca and Grafton, Ohio, derive their supply from the Berea grit overlying bituminous shale of the Lower Carboniferous age. Oil wells of Colorado are sunk in bituminous shales of the Cretaceous system. No oil is found in areas underlain by crystalline rocks, or in volcanic areas, which tends to disprove Mendeléeff's theory of its origin.

The history of the petroleum industry shows that every oil well has but a limited term of service. The current production is so slow that it is a negligable quantity. What is true of oil districts will probably be true of gas-producing districts also. From this the author infers that oil and gas are not likely to supersede coal.

**Natural Gas of Fayette County.**—Two large gas wells have recently been opened up in Fayette County ‡ and show no signs of failing. Preparations are being made to pipe the gas to Pittsburgh, and boring in several parts is being rapidly pushed forward.

**Natural Gas at Muncie, Indiana.**—There are thirty-three natural gas wells in operation near Muncie, Indiana.§ The average yield of

* *The Engineering and Mining Journal*, vol. xlviii. pp. 73, 74.
† *American Manufacturer*, vol. xlv. No. 11.
‡ *Connellsville Courier*, through *American Manufacturer*, vol. xlv. No. 4.
§ *Iron Age*, vol. xliii. p. 486.

each well is about five million cubic feet of gas a day, the largest producing well yielding about twelve million cubic feet. Assuming a considerably lower average yield than that mentioned above, the output of gas would still be equivalent to a saving in coal of some 1,500,000 tons a year. There are fifty-four factories in operation at Muncie, and the gas they consume is equivalent to about 125,000 tons of coal per annum.

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## VI.—*ARTIFICIAL GAS.*

**Classification of Fuel Gases.**—In treating of this subject Mr. H. Wurtz * divides what he calls the primary fuel gases into twenty-one classes. The first of these, termed air gases, is produced by the partial combustion of any carbonaceous combustible, and includes flue and blast furnace gases and coke oven gases. The second class is that of steam or water gas, produced by the decomposition of steam by red-hot coke. Air-steam gas or producer gas is the next class. In connection with this variety the author describes what appears to be the first producer, which was patented by Georges Michiels in 1846. Gases derived from wood, peat, lignite, and other substances form separate divisions. Hydrogen, carbonic oxide, natural gas, gas produced by the distillation of coal, and gas from oils, &c., are also subdivided. The remaining classes are made up by vapours of sulphur, phosphorus, and various metals.

**The Conversion of Coal into Gas.**—W. Schmidhammer † discusses the question, "How can coal be most economically converted into gas?" Undoubtedly it is in the blast furnace that the greatest utilisation of the heat, evolved by the combustion of the fuel, is effected, the fuel being burnt in the immediate neighbourhood of the material that is to be heated, and the ascending products of combustion giving up their heat to the descending charge of ore and fuel. In processes where the blast furnace cannot be employed, one must of necessity be content with a less perfect utilisation of the heat effected by the combustion of the fuel, either the fuel is being used cold and the charge is being subjected to a preliminary heating, in which case the highest attainable temperature

* *The Engineering and Mining Journal*, vol. xlviii. pp. 49–51.
† *Stahl und Eisen*, vol. ix. pp. 541–552.

is but low, or the waste heat is employed to pre-heat the fuel and the air to be employed in its combustion, the charge to be treated being left cold. This latter method enables temperatures to be reached which suffice for all present requirements. In order, however, to effect this pre-heating of the fuel, it has been found necessary to first convert it into gas. Attempts have been made, it is true, to pre-heat the solid fuel, but they have been unsuccessful. This gassification of the fuel is in itself simple, but it has been complicated by the efforts which have been made to utilise the heat evolved in the formation of the carbonic oxide gas in the producer, these attempts being mainly directed to the utilisation of such waste heat for the decomposition of steam passed through the ignited fuel. This decomposition of water, it must be remembered, always takes place to a greater or less extent, inasmuch as the air used in the combustion is always charged with moisture, the quantity amounting to some 5 lbs. of water for every 100 lbs. of coal converted into gas. The hydrogen or "water" gas produced by the decomposition of steam by the red-hot fuel, free as it is from diluting nitrogen, enables much higher temperature to be obtained than would otherwise be possible, but owing to the cooling action of the steam, almost five times the volume of the less valuable gas has to be produced, and as there is not always a suitable use for such gas, it is only in rare cases that water gas can be employed, especially as the necessary apparatus is costly. This difficulty has led to the oft repeated suggestion to use what is termed "mixed" gas—a mixture of water gas with the other gas also produced, suggestions which have been adopted in practice.

In order to more clearly indicate the manner in which it is possible to perfect the process employed in the conversion of the coal into gas, the author tabulates in great detail the results obtained in the case of a coal of stated composition, showing what heat is produced, and what heat is absorbed in the different reactions which take place in the producer, or is lost in one way and another. The following is the analysis of the coal:—

| Carbon. | Disposable Hydrogen. | Nitrogen. | Water Combined. | Water Hygroscopic. | Ash. |
|---|---|---|---|---|---|
| 67·65 | 2·79 | 0·41 | 11·46 | 12·65 | 5·04 |

The blast was introduced through tuyeres into a cupola-shaped producer, the gas obtained having the following percentage composition:—

| | By Volume. | By Weight. |
|---|---|---|
| Carbonic oxide | 27·99 | 30·00 |
| Carbonic anhydride | 2·01 | 3·40 |
| Heavy hydrocarbons | 0·46 | 0·49 |
| Marsh gas | 2·70 | 1·67 |
| Hydrogen | 7·82 | 0·60 |
| Oxygen | 2·17 | 2·66 |
| Nitrogen | 56·85 | 61·18 |
| Steam | 2·93 | ... |

The author adopts in his further calculations the method adopted by Baron von Jüptner,* and he shows that but a very slight gain results from blowing steam between the fire-bars of an ordinary producer, such gain being in direct proportion to the rate at which the gassification of the fuel in the producer takes place. The result, however, is very different when producers are used into which the air is forced under pressure, and in which the temperature of the fuel is much higher, but large and high producers should be employed. The author gives drawings of a modified form of producer, the mode of construction of which is based on results such as those he tabulates. Lürmann's suggestion that it might prove desirable to construct gas producers of as large size and height as ordinary blast furnaces, the author considers worthy of much consideration, as in this way alone is it possible to greatly diminish the loss of heat by radiation.

**Water Gas.**—Sketches of five different water gas producers are given by Mr. J. F. Bell,† who is of the opinion that there is no further room for designs in the forms, but only in the details of this kind of plant. An estimate is given for a new gas works producing 100,000,000 cubic feet of gas per annum. Under the most favourable conditions, the cost of plant is estimated at £3, 10s. per ton of coal carbonised, and this sum is made up as follows:—Land and producers, 16s.; engine, boilers, scubbers, &c., 10s.; meter house, station, meter, mains and valves on works, workshops, &c., 12s.; gas-holder, tanks, &c., 12s.; distribution mains and service, £1; total, £3, 10s.

Assuming that 23,000 cubic feet of water gas is made from a ton of ordinary gas coke at 10s. per ton, the cost per 1000 cubic feet is 17 pence, and is made up as follows:—Manufacture and purification, 3·0; distribution, 2·0; rates, taxes, and management, 2·8; coke, 5·2; interest and depreciation, 4·0; total, 17·0 pence.

* *Journal of the Iron and Steel Institute*, 1887, No. II. p. 236.

† Paper read before the Midland Association of Gas Managers.

**Water Gas in the United States.**—The methods of production and the plant used for the production of water gas in the United States have been very fully dealt with by Mr. A. C. Humphreys.* The author has mainly devoted himself to the consideration of water gas for illuminating purposes. Two methods are chiefly used for the production of water gas, the intermittent process, in which air and steam are forced alternately through the fuel, and the continuous method, in which the decomposing carbon is heated by external means, or in which mingled steam and air are forced through the incandescent fuel.

The history of the subject is traced from the writings of Fontana in 1780 to the present time, and about a hundred patents which have been taken out since 1823 are enumerated and discussed. Mention is made of the conflicts between water gas and coal gas in the United States. In 1874 practically no water gas was made in the States or in Canada; but, at the present time, out of 1150 gas works, 300 are on the water gas system. The theory of the process is considered in detail, and the distribution of heat throughout the reactions is calculated.

The present capacity of the water gas works at Jackson, Michigan,† is about 600,000 cubic feet per day, which is delivered at 15 pence per 1000 cubic feet. Coal slack is first coked in gas retorts heated by crude petroleum, during which 6500 feet of coal gas is obtained per ton. The coke is then transferred by shoots to two adjacent generators, where its temperature is raised to 2500° F. by air blast in two minutes. It gives 115,000 feet of producer gas, which is used for raising steam at 100 lbs. pressure. About 30,000 feet of water gas is produced for each ton of slack, and is mixed with the coal gas before purification.

The cost of coal slack is 8s. 11½d. per ton, and the oil costs 2s. 0¼d. per barrel of forty-two gallons. Twenty-three gallons of oil are used for heating, so that material costs 3·375d. per 1000 cubic feet. Labour costs 1·75d. in winter, and 2·65d. in summer per 1000 feet. Including interest, &c., the total cost falls below 12½d. per 1000 feet. Steel pipes are used for distribution. Sixty feet of gas supplies one horse-power to a gas-engine per hour, and it is stated that 20,000 cubic feet is the equivalent of a ton of anthracite.

**Loomis Water Gas.**—According to Mr. R. N. Oakman, jun.,‡ at the John Russell Cutlery Works, Turner's Falls, the daily output of

* Paper read before the Mechanical Science Section of the British Association (Newcastle Meeting).

† *Chicago Tribune*, through *American Manufacturer*, vol. xlv. No. 1.

‡ *Journal of Gas Lighting*; *American Manufacturer*, vol. xlv. No. 4.

the Loomis water gas plant amounts to 45,000 cubic feet of gas per ton of bituminous slack. These works burned three tons of anthracite daily to heat steel in their small forges; they now burn 4800 lbs. per day of bituminous slack for heating the steel and a 50 horse-power boiler. To do the same work, 8000 lbs. of anthracite would be required for steel heating, and 4200 lbs. of bituminous coal for raising steam. Allowing for coal used to raise steam in the gas works, the net gain is 5200 lbs. of fuel per day. From 35 to 45 per cent. of the gas is combustible.

Other plants of this kind are in use with success at a saw and steel-works in Philadelphia, and at the works of the Waltham Watch Company.

**Dawson Gas.**—According to E. Schilling,* this gas, which was introduced by Dawson in 1883, is largely used in Germany for heating purposes and for working gas motors. It is prepared by passing superheated steam, with a certain quantity of air, through an injector under the grate of a producer that is filled with anthracite. The gas is thus a mixture of producer gas and water gas. The percentage volumetric composition of the gas, compared with that of other varieties of gas, is as follows:—

| | $CO_2$. | CO. | $H_2$. | $CH_4$. | Heavy Hydrocarbons. | $N_2$. | Heating Value. |
|---|---|---|---|---|---|---|---|
| Illuminating gas | 1·6 | 9·6 | 49·6 | 30·7 | 4·7 | 3·8 | 5379 |
| Coke producer gas | 4·5 | 25·7 | trace | ... | ... | 69·8 | 773 |
| Normal producer water gas | 8·8 | 23·2 | 12·7 | ... | ... | 55·3 | 1026 |
| Producer water gas with excess of steam | 14·2 | 16·0 | 19·9 | ... | ... | 49·9 | 1009 |
| Dawson gas | 6·0 | 23·0 | 17·0 | 2·0 | ... | 52·0 | 1313 |
| Water gas | 2·7 | 43·8 | 49·2 | 0·3 | ... | 4·0 | 2884 |

**The Archer Gas-Producer.**—The Archer water-oil gas-producer occupies a space of about 6½ feet square. It is fed with crude petroleum, forced in by a very small pump from an iron tank having a capacity of 5000 gallons. During its passage from the pump to the producer, the oil is heated by passing through a coil of heated pipes. On reaching the vaporisers, the oil is brought into contact with superheated steam in the proportion of one part of oil to three parts of steam. The instant the gas is made it passes through 2¼-inch pipes

* *Journal fur Gasbeleuchtung und Wasserversorgung*, vol. xxxii. pp. 424-432.

into chequer-work chambers. The arrangement of these chambers is similar to that generally adopted.*

**The Taylor Gas-Producer.**—The gas-producer designed by Mr. W. J. Taylor has a revolving flat circular bottom, which, in its revolution, discharges the ash and clinker over its edge into a sealed ash-pit. A mixture of air and steam is used, the conduit for air and steam acting as a central support on which the bottom revolves. A Körting jet steam-blower is employed. It is stated that one ton of buckwheat anthracite will yield, in this producer, 166,000 cubic feet of gas, affording about 135,000 heat units per 1000 cubic feet. The composition of the gas produced is as follows:—

| | Per cent. |
|---|---|
| Carbonic oxide | 23·0 to 27·5 |
| Hydrogen | 15·0 ,, 10·5 |
| Marsh gas | 1·0 ,, 2·0 |
| Carbonic anhydride | 1·0 ,, 3·0 |
| Nitrogen | 60·0 ,, 58·0 |

The producers are constructed in sizes from 4 to 6 feet in internal diameter, and will convert into gas from 2½ to 5 tons of coal in 24 hours.†

## VII.—*COAL MINING.*

**Coal Mining in Nova Scotia.**—A very full account is given by Mr. E. Gilpin ‡ of the coal-mining industry in Nova Scotia. The first notice of coal was not published until 1672, though the outcrop on Cape Breton is visible at sea for miles. In 1711 considerable amounts were taken away, and in 1720 the first regular mining operations were begun. An interesting account is given of the history up to the present time. Nova Scotia coal sales from 1785 to 1887 are shown by decades in the following table:—

| Year. | Tons. | Year. | Tons. |
|---|---|---|---|
| 1785 to 1790 | 14,349 | 1841 to 1850 | 1,533,798 |
| 1791 to 1800 | 51,048 | 1851 to 1860 | 2,399,829 |
| 1801 to 1810 | 70,452 | 1861 to 1870 | 4,927,339 |
| 1811 to 1820 | 91,527 | 1871 to 1880 | 7,377,428 |
| 1821 to 1830 | 140,820 | 1881 to 1887 | 8,992,226 |
| 1831 to 1840 | 839,981 | Total for 1887 only | 1,519,684 |

* *Iron Age*, vol. xliv. p. 124.
† *Ibid.*, vol. xliii. p. 805, 1 illustration.
‡ *Transactions of the Canadian Society of Civil Engineers*, vol. ii. pp. 350–400.

The coal of Nova Scotia is bituminous and frequently coking. The Cape Breton seams dip about 1 in 10, and vary from 4 feet 9 inches to 9 feet in thickness. The Pictou and Cumberland pitch about 1 in 3; the thickness of the former varies from 4 to 15 feet, of the latter from 3½ to 11 feet. The earliest methods of mining in the Pictou district have already been described by the author. In the present system a "balance," 10 feet high and 10 feet wide, is driven to the rise for 450 feet with parallel air ways. Two 2-foot tracks are laid in the balance, and act as an inclined plane for lowering the coal to the level. The pillar above the level is left 50 feet thick, and the succeeding pillars are 35 feet thick, spaced 12 to 15 feet apart. The bords run level for about 150 yards to the next balance, and communicate by cross cuts every 60 feet. If the seam pitches more than 25°, the coal is run down on the floor or a sheet iron shoot in the balance. When local conditions permit, the seams are opened by slopes from which the mine is worked as from a shaft. In the flatter seams of Cape Breton the methods of mining do not differ materially from those adopted in the United Kingdom.

Examples of the sizes of pillars are given. At present the most advanced practice is in favour of moderate-sized pillars to be drawn at the earliest possible moment. As shipments are interrupted in the winter, extensive and systematic pillar workings are not carried out at considerable depths. When the pillars are not taken out, the percentage of coal removed varies between 25 and 30 per cent.; when they are drawn, as much as 90 per cent. of the seam has been gained.

Most of the pits are still ventilated by furnaces; the first fan to be introduced was a Guibal in 1871, at the Albion mines. In some pits blow-down fans are used. The Cumberland and Cape Breton seams are very free from gas, with the exception of three collieries, so that naked lights and powder are used. The Pictou seams, on the other hand, are decidedly fiery.

Tables are given showing details of the principal ventilators, pumping and winding plant, and dimensions of pit tubs. As a general rule, even in submarine workings, the mines are fairly dry, but many of them have to deal with the drainage from old pillar workings. In some mines the water is very corrosive; one analysis showing 1·48 part per 1000 of sulphuric acid. In 1885, 1,352,205 tons of coal was raised, and 3,646,889 tons of water pumped. The speed of winding is generally low owing to the slight depth of the shafts, and in the slopes

it is limited by the speed at which the tubs can run down. The tubs hold from ½ to 1¼ ton of coal.

After referring to the means for transportation, the author refers to the prices of labour. In the Pictou and Cumberland districts the bords are driven level, but in the flatter Cape Breton seams advantage is taken of the cleat. The coal is holed under for 3 or 4 feet, and a shot in the upper fast corner brings down the coal. In the thicker seams a layer of 3 to 4 feet is taken off near the roof, and then the rest of the coal is lifted in two benches. Tabulated statements are given of the number of men employed, with their average production, and of the total output and costs in each colliery.

Fuller details are given of the Springhill Collieries in the Cumberland district by Mr. R. W. Leonard.* This mine is worked by the bord and pillar system with the balances mentioned above. A heavy fault occurs in the seam, and is shown on plans accompanying the paper. A 6-inch bore hole, 600 feet deep, has been put down for conveying power into the mine. For this purpose compressed air will probably be used.

**Anthracite Mining.**—The adoption of the longwall system in American anthracite mines is strongly urged by Mr. W. S. Gresley.† By the present pillar and stall system some 40 to 50 per cent. of the entire seam is lost. When the coal lies at a moderate angle, and is fairly free from faults, basins, and such like, especially when the seams are thick, or lie close together, then the longwall withdrawing system is certainly applicable. The author describes the longwall system in detail, giving plans and sections. The great advantages of the system, and its adaptability to many seams now being worked, are pointed out, and estimates are given of the cost.

**Longwall Working at the König Colliery.**—J. Sprenger‡ gives a lengthy description of the method of longwall working that has been adopted at the König Colliery, at Neunkirchen (Saarbrücken). The advantages presented by this system, used in conjunction with self-acting planes, are considerable. The transport of refuse at the surface is dispensed with, and the coal may consequently be raised more rapidly. The purchase of land for the extension of the spoil

* *Transactions of the Canadian Society of Civil Engineers*, vol. ii. pp. 404-413.
† *The Engineering and Mining Journal*, vol. xlviii. pp. 136-140.
‡ *Berg- und Hüttenmännische Zeitung*, vol. xlviii. pp. 295-298, 305-308.

bank is no longer necessary. There is a larger proportion of lump coal. The ventilation is very simple and inexpensive, and accumulations of fire-damp are avoided. The getting of the coal is easier. Lastly, no landslips can take place in the superincumbent strata, but merely a small subsidence, since the roof rests on the pack-walls.

**Shaft Sinking by the Kind-Chaudron Method.**—M. J. Chaudron* gives a list of shafts sunk by the Kind-Chaudron method since 1878. There are five in Belgium, three in France, one in England, and seven in Germany, or sixteen altogether. Full details and illustrations are given of three of the more important. A new departure was made at the collieries of Gneisenau, Westphalia, by lining the shaft only where it passes through water-bearing strata. This was done by closing the lining with a diaphragm, both at the top and bottom, so as to obtain an air-tight vessel into which water could be admitted as desired to control its buoyancy. In order to be certain of stopping out all the water, the lining was carried upwards for a distance of about 82 feet above the water-bearing strata, which were 142 feet thick.

At the salt mines of Thiederhall, Brunswick, great difficulty was experienced owing to running ground. No less than eight separate linings had to be used, each one just overlapping the next, so that the shaft is reduced in diameter from 13 feet 9 inches to 10 feet 3 inches, at a depth of 354 feet.

The Kind-Chaudron method of boring shafts has been successfully carried out, for the eighth time in Germany, at Leopoldshall.† Several attempts to sink a new shaft having failed on account of the influx of water, the Kind-Chaudron method was adopted, and the shaft completed in 17 months. The small shaft was sunk with a borer 8¼ feet in diameter and about 16 tons in weight. For the subsequent boring down to the impermeable strata, a tool, 14 feet in diameter and 20 tons in weight, was employed.

**The Poetsch System of Sinking Shafts.**—In a paper read before the German Mining Congress at Halle, the inventor of this system referred to the great extent to which it had been adopted, and stated that in 1890 nine shafts were to be sunk by its aid, two of these being in Staffordshire, and another for the purposes of permanent exhibition at Berlin.

* "*Le Système Kind et Chaudron pour le fonçage de puits.*"—Excerpt from *L'industrie Moderne.* Brussels, 1889.

† *Zeitschrift des Vereines deutscher Ingenieure*, vol. xxxiii. p. 975.

H. Stefan * gives a historical sketch of the rise and progress of the Poetsch system of shaft sinking. Mention is made of the various shafts which have been sunk by the aid of this process, and attention is drawn to the modifications of the process which have from time to time been introduced.

**Sinking Appliances at Llanbradach.**—Mr. W. Galloway † has published a lengthy paper, accompanied by plans and drawings, describing the sinking at Llanbradach that has been undertaken by the Cardiff Steam Coal Collieries Company, Limited, for the purpose of winning and working the well-known steam coal seams of the district. The company decided to sink a shaft to ascertain the exact depth of the steam coals, and to serve as an upcast to the future colliery, before deciding upon the more important equipment of the principal winding shaft.

**Koepe System of Winding.**—The Koepe system of winding is briefly described by Mr. J. H. Harden, ‡ who states that a new system, which is believed to be a modification of this, has been adopted in Pennsylvania and is called the Poore system. § Mr. H. W. Hughes ‖ states that the Koepe system has been discontinued at the Bestwood Colliery owing to difficulties connected with the slipping of the rope after oiling. This defect is especially objectionable at Bestwood, as the engineer has to rely on the indicator. At the Hanover pit and at the Sneyd collieries the system has given satisfaction, the life of the rope is greatly increased, and no accident has occurred.

**The Equalisation of Load on Winding Engines by the Employment of Spiral Drums.**—Mr. E. M. Rogers ¶ points out that the employment of conical drums cannot compensate the altering length of the rope for all positions of the cage, and proceeds to determine analytically the shape of the curved surface or spiral of a pair of drums which will give an exact balance of the ropes and cages in all positions.

If the system is perfectly balanced when one rope is entirely wound

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xxxvii. pp. 292-295.
† *Proceedings of the South Wales Institute of Engineers*, vol. xvi. pp. 107-124.
‡ *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 429-431.
§ *Journal of the Iron and Steel Institute*, No. 1, 1889, p. 274.
‖ *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 431-432.
¶ *Ibid.*, pp. 305-313.

on one drum, and the other entirely unwound, the drums must be so shaped that any increment of weight due to change of rope length, together with the corresponding increment of radius, will make the moments about the axis equal.

The problem is solved as follows :—

Let $a$ = radius of smaller end.
$a'$ = radius of larger end.
$k$ = weight of cage.
$W$ = total weight of either rope.
$w$ = weight per unit length of rope.

Then, when one rope is totally wound and the other totally unwound—

$$(W + k)\, a = ka',$$

after one revolution ($k$ + weight of one turn of rope at large end) × (radius after one revolution at large end) = ($k$ + $W$ − weight of one turn of rope at small end) × (radius after one revolution at small end), *i.e.*, the moments at initial positions, and after one revolution, must be equal by hypothesis. Considering the drum as continuous, take a point at which the radius is unity, then the weight of rope and cage at that point must equal the constant moment (say $M$), since $M \times 1 = M$. Therefore, for $M$ to remain constant, the weight of rope and cage at any point of radius $r$ must be $\frac{M}{r}$, because $\frac{M}{r} \times r = M$. Let the drum be unwound to a position at which the radius is $r$, and be supposed to rotate backwards and forwards through an infinitely small angle corresponding to an arc = $dv$, then the radii will be $r + dr$ and $r - dr$ respectively.

Then $$(r + dr)\left(\frac{M}{r} - i\right) = M,$$

and $$(r - dr)\left(\frac{M}{r} + i\right) = M,$$

where $i$ is the increment of weight of the rope, corresponding to $dv$. Therefore $(r + dr)\left(\frac{M}{r} - i\right) = (r - dr)\left(\frac{M}{r} + i\right)$. . . . (1). The expression for the differential of arc of a spiral in terms of the radius and arc of revolution is—

$$dz = \sqrt{dr^2 + r^2dv^2}.$$

Where $z$ = arc of spiral, $v$ = arc of revolution referred to unit radius,

and $r$ = radius of spiral. Substituting this value in equation (1) it becomes

$$(r + dr)\left(\frac{M}{r} - w\sqrt{dr^2 + r^2dv^2}\right) = (r - dr)\left(\frac{M}{r} + w\sqrt{dr^2 + r^2dv^2}\right)$$

which reduces to

$$\frac{Mdr}{r} = rw\sqrt{dr^2 + r^2dv^2}.$$

Squaring it becomes

$$\frac{M^2dr^2}{r^2} = r^2w^2\,(dr^2 + r^2dv^2).$$

or

$$r^4dv^2 = \left(\frac{M^2}{r^2w^2} - r^2\right)dr^2$$

$$\therefore\; r^2dv = dr\sqrt{\frac{M^2}{r^2w^2} - r^2} \quad \ldots\ldots\ldots (2)$$

whence

$$dv = \frac{dr\sqrt{\frac{M^2}{r^2w^2} - r^2}}{r^3} = \frac{dr\sqrt{\frac{M^2}{w^2} - r^4}}{r^3}$$

and

$$\int dv = v = \int \frac{dr\sqrt{\frac{M^2}{w^2} - r^4}}{r^3}$$

Integrating this the author obtains—

$$v = -\frac{\sqrt{\frac{M^2}{w^2} - r^4}}{2r^2} - \tfrac{1}{2}\sin.^{-1}\frac{wr^2}{M} + \text{constant}$$

$$\text{If } v = \int_{r=a}^{r=a} dv \text{ then } v_{r=a'}^{r=a} = \frac{\sqrt{\frac{M^2}{w^2} - a^4}}{2a^2} - \frac{\sqrt{\frac{M^2}{w^2} - a'^4}}{2a'^2},$$

$$+ \tfrac{1}{2}\sin.^{-1}\frac{wa^2}{M} - \sin.^{-1}\frac{wa'^2}{M} \quad \ldots\ldots (3)$$

For ordinary values of $a$ and $a'$, the last two terms may be neglected, on account of their smallness. By substituting different values for $a$ and $a'$ in (3), and making $v = 2\pi n$, and solving with respect to the number of revolutions $n$, a curve may be plotted which will show the value of the radius for various numbers of revolutions, and will represent an outline section of the drum fulfilling the conditions of the pro-

blem. The total length of the rope is then calculated, the following value being obtained:—

$$z = dz = \int \frac{Mdv}{wr^2} = \int \frac{Mr^{-2}\,dr}{w} = -\frac{M}{wr} + \text{constant}$$

$$z\Big|_{r=a'}^{r=a} = \int_{r=a'}^{r=a} dz = \frac{M}{wa} - \frac{M}{wa'} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

A result, it is pointed out, that might naturally have been expected, since it has already been shown that the weight hanging at any position of the drum is $\frac{M}{r}$. A special case is worked out, and a curve plotted, it being noted that though the above investigation is not rigorously correct, since the expression

$$dz = \sqrt{dr^2 + r^2dv^2}$$

is for a plain spiral, and not for a curve of three dimensions, the error is slight if the spiral is considered as wound round a drum of constantly increasing radius. Two cases are plotted; one in which the "pitch" of the spiral is uniform, and the other where the "pitch" increases uniformly from the small to the larger end: the positions being obtained by laying off assumed values of $a$, and finding the corresponding values of $n$.

**Pumping Machinery in Nova Scotia.**—Owing to the methods of working in the Pictou seams in Nova Scotia, it is sometimes necessary to raise the water from considerable depths. A description of the pumping plant at the Arcadia slope, Westville, is given by Mr. H. S. Poole.* A duplex compound condensing Knowles' pump is placed at the 2400-foot level to pump to the surface, through 2400 feet of tubing or a vertical height of 977 feet, against a pressure of 435 lbs. per square inch. The cylinders are pairs of 22 and 12 inches; the four plungers have diameters of 5½ inches, and the stroke is 24 inches. Steam at 105 lbs. pressure is conveyed through 2600 feet of covered 4-inch pipe, with a loss of 10 lbs. Expansion joints are replaced by bends and circles in the pipe every 400 or 500 feet, and leaky joints are thus obviated. A small air chamber is used on the pump.

* *Transactions of the Canadian Society of Civil Engineers*, vol. ii. pp. 401–403.

**Timbering in Mines.**—The method of timbering in the mines at Commentry is fully described by M. Planchard,* with details of cost. In 1878 it was attempted to use old rails as head pieces; the best results were attained when they were placed edgeways, but they were very liable to breakage. Iron bars of rectangular section, 3·15 by 1·18 inches and 12 feet long, were ultimately adopted in preference to V and other sections, as they are easily straightened, and great rigidity is not necessary.

The cost per ton with various methods is as follows:—Ordinary timbering, 4½d.; timbering with wooden cap pieces of 10 feet, 2¾d.; timbering with iron cap pieces placed perpendicularly to the face, 2d.; and timbering with the caps parallel to the face, 1½d. In the last two cases the cost includes ½d. for amortisation and the re-straightening of the iron bars.

Some of the bars have been used 200 times; breakages are rare, as the iron bends instead of breaking like timber.

**Enlarging Bore-Holes.**—In the device of Messrs. Plom and d'Andrimont † a tube is placed in the bore-hole, and inside this fits the boring bar, which is spirally grooved to work out the debris. A pair of reamer bits are pivoted on the inner end of the bar, and are forced outwards gradually by a screw sleeve attached to the outer end of the tube so as to enlarge the end of the bore-hole.

**Endless Rope Haulage.**—Mr. T. H. Bailey ‡ shows that the importance of efficient haulage to the mining industry of the present day can scarcely be over-estimated, as the coal easily reached near the surface has been exhausted in most of the large coalfields of the country, and at the greater depths now necessary colliery owners are compelled to adopt various systems of underground haulage. The two most important features with reference to efficient haulage are the gradient and the friction of the conveyance carrying the load. The particular method under description is the endless rope system, which had been laid down in the South Duffryn Colliery at the Plymouth Works, Merthyr Tydvil. A packing of sand behind a brickwork lining of the archway is found to be a sure means of preventing local pressure from the surrounding strata. The whole of the underground engines and pumps required are worked by compressed air. In the Plymouth

* *Société de l'Industrie Minérale, Comptes Rendus Mensuels*, 1889, pp. 85-91, with plates.

† *The Colliery Manager*, vol. v. p. 145.

‡ *Proceedings of the South Wales Institute of Engineers*, vol. xvi. pp. 94-106.

colliery the rope is carried under the trams, and the other disadvantage of the system is that to apply it economically two lines of railway are required, and consequently very wide roads are needed to accommodate the large trams used in South Wales. The hauling engines in use show a total indicated power of 18 horse-power exerted on the cranks. At the present time there are fifteen full trams and fifteen empty trams attached to the rope, about forty yards apart, and the engines make twenty revolutions per minute. The rope travels about $1\frac{1}{3}$ mile per hour.

**Use of Electricity in Mines.**—A report on the use of electricity in mines has been presented to the International Congress of Mines and Metallurgy at Paris by M. Chalon.* Its use in metal mines is especially valuable, as fuel is not always available, whilst water-power can generally be obtained for driving the dynamos. In some cases it is possible to sink a well in order to obtain an artificial fall.

The firing of blasts is the oldest application of electricity. This, besides being more economical, avoids the danger incurred in the use of safety and other fuses. The expenses of electric firing in sinking a shaft 1640 feet deep are as follows:—

| | £ | s. | d. |
|---|---|---|---|
| Expense of material and magneto-machine . . . . | 3 | 4 | 0 |
| Conductor, consisting of two insulated wires bound together | 3 | 4 | 0 |
| Installation and sundries . . . . . . . . | 1 | 0 | 0 |
| | £7 | 8 | 0 |

The cost of firing when powder is used is:—

| | d. |
|---|---|
| Simple primer with a yard of double conducting wire . . . | 1·00 |
| Iron coupling wire covered with cotton at 13 pence per lb. . . | 0·04 |
| | 1·04 |

When dynamite is used the expense is one halfpenny more. The expenses after allowing for wire recovered after blasting show the expense per shot to be:—

| | Using Powder. | Using Dynamite. |
|---|---|---|
| | Pence. | Pence. |
| Materials and plant . . . . | 0·20 | 0·20 |
| Working expenses . . . . | 0·94 | 1·44 |
| | 1·14 | 1·64 |
| Ordinary fuse . . . . . | 0·65 | 1·10 |
| Guttapercha fuse . . . . . | 2·50 | 2·95 |

* *L'Électricité dans les Mines.* Sainte-Étienne, 1889.

Lighting in mines consists of two kinds—lighting by fixed and by portable lamps. The use of portable lamps underground is greatly to be preferred, as there is more danger of breaking the switches or the insulation of the cables in permanent installations. Mention is made of the various forms of lamps and also of fire-damp indicators. When there is already a good electric plant, there are certain advantages in the use of lamps with secondary batteries, but in all other cases a good primary lamp is preferable. It cannot be said, however, that a really good and practical primary lamp has yet been devised.

Signalling in mines by the aid of electricity is made use of with great advantage, and only a simple code is required. Work in the shaft is easily controlled by a system of electric signals.

Machine boring and mechanical cutting are also performed by electric motors. The operation of boring by percussion with electricity offers great difficulties, but some interesting experiments have already been carried out in the United States. The application to rotary boring is easier. Electrical cutting machines, too, have already been successfully tested, notably the Bowes, Blackburn and Mori, and the Lechner machines.

**Electrical Transmission of Power for Mining.**—When weight is an object, according to Mr. A. T. Snell,* one horse-power per 70 lbs. of motor can be developed, but it is preferable to employ 100 to 120 lbs. After referring to the Normanton plant, the author describes the hauling and pumping plant at Llanerch Colliery, near Pontypool, Monmouthshire. For operating a single rope hauling engine by electricity the dynamo on the surface is driven by a horizontal engine with 18-inch cylinder and 3½-foot stroke, running at 50 revolutions, with a steam pressure of 50 to 60 lbs. The current is conveyed by a copper cable of 19 strands No. 18 BWG, insulated and covered with lead. The motor is situated 750 yards from the pit, which is 250 yards deep. The haulage is effected by an old type machine previously driven by a single engine but now converted. Two drifts are worked with inclines of 1 in 8 and 1 in 12 respectively, and each is about 300 yards long. A loaded tram weighs 29 cwt. Signals are given by a "rapper." Testing instruments show the driver if the tram is off the line, and give him warning of other accidents. The rolling friction on the road averages 70 lbs. per ton, and about 5 horse-power is absorbed by the

* Lecture at the Mining School, Wigan, *Iron and Coal Trades Review*, vol. xxxix. pp. 455–456.

drum and ropes. The electrical losses are small, but full data have not been given, and the total efficiency is therefore calculated at 48·5 per cent. When desired, the hauling engine can be thrown out of gear, and the motor used to drive the pumps.

Mr. A. T. Snell also describes a small pumping plant at the Andrew's House pit, which has replaced two "cranks," each equipped by eight horses. The main lead is about a mile long and composed of copper; the return wire is an old iron rope. The water is delivered to a height of 44 feet at a distance of 750 yards. The dynamo is driven by an engine with a horizontal cylinder 12 by 24 inches, and running at 38 revolutions per minute.

At Linlithgow a 4 or 5 horse-power dynamo is driven by an engine, and the current is carried by a bare cable to a quarry $1\frac{1}{4}$ mile distant. Water is lifted through a rise of 135 feet to a distance of 600 yards at the rate of 33 gallons per minute. The loss in the cable is about one horse-power. The pump house is visited once a day only for lubrication, &c. Other plant which may be used for pumping is also referred to.

Mr. G. W. Mansfield * shows that the electric system is the simplest method of transmitting power, and that it is sufficiently advanced to be employed profitably either over short or great distances. A table is given showing the cost of a complete plant for transmitting from 100 to 500 horse-power over any distance up to 100 miles. The author then considers the application of electricity to boring and excavating, hoisting, hauling, transporting, pumping, ventilating, and other mechanical work. The small attention required by the wires, and the handiness of the motor, is a general recommendation. For ventilation, small fans worked by motors could be placed in each heading, or a mine could be entirely ventilated by several small fans instead of one large one. Examples of haulage and pumping operations are also quoted.

**Coal Mining by Machinery.**—In Illinois, according to a report by Mr. J. B. Lord,† in 1888 there were 272 machines at work for mining coal. With them, 3088 men produced 2,243,210 tons of lump coal, or 20 per cent. of the total production. Of these machines, 245 are of the Harrison type, 17 are the Legg or Lechner machines, and 10 are the Yock machines. Owing to the thorough division of labour which

* *Transactions of the American Institute of Mining Engineers*, vol. xvi. pp. 851–862.
† *The Colliery Manager*, vol. v. pp. 144–145.

the use of machinery induces, it is more likely that both timbering and blasting are efficiently performed.

**Coal Cutting by Electricity.**—In a paper read before the British Society of Mining Students, Mr. H. W. Hughes * discussed the use of electricity as a motive power in collieries. The author pointed out that many dynamo machines have an efficiency of over 90 per cent., and that many motors are equally efficient. Referring to the advantage of using currents of relatively high volt power, he observes, that as one of the main sources of expense lies in the copper conducting wires, it is of importance to remember the rule that the cost of copper for line wire varies in the inverse ratio of the square of the voltage employed. This is shown in the following example: If 2000 lbs. of copper wire are required for a current of 50 volts, only 125 lbs. will be required if the electromotive force is increased to 200 volts. To avoid the possibility of sparks and danger to human life should the conducting wire be accidentally broken, it is necessary to keep the volt power within certain limits, from 500 to 700 volts being usually considered the maximum limit of safety, though the author thinks that this limit might be considerably exceeded.

Experiments have been carried out in this country, at a colliery near Leeds, to drive a coal cutting machine by electricity, but the trials have been suspended, owing to a break-down in the machine. In the United States, two installations have been put down with marked success. The machines used, although not identical, are similar in construction, and consist of a horizontal cutter bar armed with small steel knives set in a spiral, a semi-cylindrical cut being made at each revolution. This bar is generally about 3 feet long, and can be pushed forward by an arrangement of levers about 5 feet, so that 15 square feet ought to be undercut from one position of machine, but in practice about 13½ square feet is the usual amount. The driving machinery, when compressed air is used, consists of a duplex engine, geared down 4 to 1 to reduce speed, and this drives a central chain belt connected with the cutter bar, and giving it a rotary motion. Two small link belts complete the outfit, one on either side of the cutter bar; these are provided with short projections, and push back the cuttings produced by the steel knives, and keep the undercut free for the advancement of the machine. Depth of undercut about 5 inches. After completing one holing, 5 feet under, the machine is withdrawn and

* *The Journal of the British Society of Mining Students*, vol. xi. pp. 127–132.

pushed along the face by crowbars over the length of cutter bar used, and is then in the required position for making the next cut. The only difference made when using electricity is to substitute an electrical motor for the small pair of engines.

The first installation was made at Drane Colliery, near Osceola, in Pennsylvania. The engine driving the dynamo is an old one of about 25 horse-power, and is very defective, having passed through two fires. The wires are carried into the workings, a distance of about 1000 feet, on pegs driven into holes bored into the coal along the roadways. Even with such a temporary arrangement no difficulty arose, as the machine commenced work immediately the current was turned into it. A 10 horse-power Sprague motor is used and mounted on a truck, and as the weight is about 1000 lbs. it can be easily moved. Connection between the motor and machine is made by a tarred hemp rope running in V-shaped grooves on the motor and cutter sheaves. The connection is made of sufficient length that the motor can be operated 50 feet away from the cutter; the advantage of joining the motor to a machine by a flexible connection, instead of placing both on one bed plate, is that the machine is made much lighter, and complete absence of the objectionable vibration set up by engines is specially noticeable. By means of suitable jacks carrying pulleys, the cutter can be operated at any angle from the motor, the connection being made taut by a movement of the motor truck to the required position. Two men are needed to work this machine, and these two men are excavating 100 tons of coal in 10 hours, and do not require any additional aid in moving the machine from one position to another. Seventy per cent. of the primal energy is given off for work from motor pulleys to the cutter. The cost of the electrical equipment for this installation, including dynamo, motors, and conductors, was £320.

The second installation is at the Morris and Ellsworth collieries in Ohio, and here the motor is placed directly on the coal cutting machine, and occupies the place of the air cylinders; it is claimed to be less expensive than the air machines, more effective in its operation, and much more easily handled.]

**Coal Mining Machine.**—The Jeffrey electric coal mining machine* consists of a frame carrying the motor. A sliding frame is fed forwards in the fixed frame by racks and pinions, and the cutter shaft extends across the front of the travelling frame. It is claimed that it

* *The Engineering and Mining Journal*, vol. xlviii. p. 5.

will undercut the coal 6 feet deep by 3 feet wide in five minutes, the height of the holing being 4 inches. In one case as much as 1200 square feet has been cut in ten hours.

**Mining Wedges.**—The "Emperor" mining wedge is cylindrical in shape, 3 inches in diameter for hard coal and $3\frac{1}{2}$ inches for soft coal. It consists of a hydraulic chamber with a number of transverse rams which are forced outwards to force apart the base and cover plate. The rams at the back of the hole are larger than in front, so as to exert more pressure there. A special coupling is used to connect the appliance to the pump.*

In the "Samson" coal-getter, a screw bears in a block at the far end of the hole, and draws the top wedge over the bottom wedge-shaped shoe. By this arrangement the part of the screw that is in compression is very short and not likely to bend.†

**Colliery Ventilation.**—Mr. A. L. Stevenson ‡ has classified some of his observations on fans of the Guibal, Waddle, and Schiele types, and presents his results in tabulated form. The situation, size, and number of revolutions of each fan is given, also the observed and calculated water-gauge, and the efficiency. The average efficiency of these three types by the author's observations is respectively 65, 44, and 40 per cent., the superiority of the Guibal being clearly due to its expanding outlet.

M. Rateau § gives an account of experiments with a new form of fan used for supplying air. The fan has taper blades, and draws air in at the centre through a conical inlet, and discharges it into a circumferential conduit which gradually increases in diameter.

M. Mortier ‖ also describes a fan with blades which are carried round in a casing, and are kept parallel to each other by apparatus similar to that used for the feathering floats of paddle-wheels.

A further contribution to the theory of centrifugal ventilators is made by Mr. J. Henrotte.¶ It deals solely with the mathematical side of the question.

* *Iron*, vol. xxxiv. pp. 201, 202.

† *The Colliery Guardian*, vol. lviii. p. 912.

‡ *Engineering*, vol. xlviii. pp. 242, 243.

§ *Société de l'Industrie Minérale, Comptes Rendus Mensuels*, 1889, pp. 140-145, with plates.

‖ *Ibid.*, 1889, pp. 145-150, with plate.

¶ *The Colliery Guardian*, vol. lvii. p. 839.

**Dust in Mines.**—The question of dust in mines, with some of the causes of production and methods of counteracting it, is reviewed by Mr. M. Mercier.* Dust is produced by the working and getting of the coal at the faces, by the disintegration of pillars and scattered coal, and by leakage from tubs and boxes. In the longwall system, these first two factors are the least active, so that the main improvements must be made in the mode of haulage and form of tubs. The tubs should be made of well-seasoned timber with grooved or covered joints, and steel or sheet iron boxes should be used. Wooden or rubber buffers should be used to reduce shocks, and some system of haulage with low rate of speed is preferable.

After thus pointing out the causes and means for partly overcoming the production of dust, the author proceeds to investigate the means of removing or destroying its dangerous properties. Raising the temperature of the intake air is out of the question. Strewing the workings with salt or brine gives good results if 1 lb. per superficial yard is distributed once a month, but both the salt and labour required are expensive, and the roof and sides are not efficiently damped. Exhaust steam has a pernicious effect on shale, and so is not likely to be used. The only methods left are those of watering by carts or by pipes. The best form of cart for this purpose has a disc or rose which rapidly revolves when the cart is in motion, and throws the water over the floor, sides, and roof. The disadvantages of this system are the cost of conveying the cart about and of keeping up the roads in the return air courses. The second available system is the use of pipes with jets every ten or twenty yards. In this method the water can be turned on when desired to any part of the mine, and can be extended readily by flexible hoses. It might be useful in case of fire. On the other hand, the first cost and the maintenance are heavy.

In conclusion, there are several points to be considered. Is it necessary to water the mine, except in the main haulage roads and the return airways near the shaft? What will be the result of damping the floor in mines subject to creep? Will sprays at specified intervals be effectual, and should salt be dissolved in the water? The advisability of hanging damped cloth over shot-holes when firing, of reducing the air velocity, and of dividing the mine into sections, are also points that require attention.

**Electric Lighting in Mines.**—Mr. T. M. W. Wallis † gives par-

* *Transactions of the National Association of Colliery Managers*, vol. i. pp. 94–98.

† Paper read before the Chesterfield and Midland Counties Institution of Engineers.

ticulars of the electric light installation at the Corsall Colliery, Newark. Excluding labour, the cost is reckoned at £61 for 222,000 lamp hours, the lamp giving a light of 16 candle-power. The cost is made up as follows:—Coal, £8, 5s.; renewals of lamps, £27, 15s.; interest and depreciation, £20; oil, waste, &c., £5. Under similar conditions, gas is estimated to cost £150. A list is given of forty-six collieries now using the electric light.

Mr. A. F. Guy * gives the approximate cost of lighting a colliery 400 feet deep. The plant consists of 75 glow-lamps of 16 candle-power, burning 9000 hours, and two arc lamps of 1000 candle-power each on the surface, burning for 500 hours. The cost of the plant is given as £269, and the annual working cost is £93, taking coal at 5s. per ton, interest 5 per cent., depreciation 10 per cent., and labour, &c., £20.

An electric miner's lamp with a primary battery has been described by Mr. E. T. Boston.† The cell is of guttapercha, and the elements are zinc and carbon. The lamp is placed on the top, under a thick glass dome, so as to cast no shadow on the roof. The weight is 2¼ lbs., cost one penny per shift when giving 2½ candle-power for ten hours, and the total first cost need not be more than £1.

**Safety Lamp Experiments.**—A report of the committee appointed to carry out a series of experiments on lamps at the Cymmer Colliery, Rhondda Valley, has been published.‡ The safety of the shielded Clanny lamp was tested in various currents of explosive mixture. Gas from a blower was used, and maintained at an even pressure in a holder whence it was delivered with air at a distance of 9 feet from the lamps. At this distance the admixture of air and gas was perfect. The mixture used contained 9·5 per cent. of gas in all cases. Several varieties of lamps were tested, none of which did the committee feel themselves justified in recommending. The two-thirds shielded Clanny is pronounced to be unsafe in the high velocity of the air currents in the Rhondda district.

**Safety Lamps.**—At the Mining and Metallurgical Congress recently held at Paris, M. H. Le Chatelier reviewed the present status of some of the more important lamps, and his report was followed by a vigorous discussion. M. Fumat showed an improved form of his

* *The Colliery Guardian*, vol. v. p. 143.

† *Proceedings of the South Wales Institute of Engineers*, vol. xvi. pp. 266-267, with plate.

‡ *Iron and Coal Trades Review*, vol. xxxviii. p. 622.

lamp which remains alight in strong draughts. M. Le Chatelier reported that this is the first lamp with ascending air current which becomes extinguished in explosive mixtures, as far as he was aware.

The question of fastenings was fully discussed. It was generally agreed that no form of key fastening could be allowed, as the key can soon be duplicated. Lead rivets or soldering give decidedly better results, especially if a record be kept of workmen who habitually bring back broken fastenings. Still safer are hydraulic and magnetic fastenings, as the miner cannot undo them without breaking the lamp. The hydraulic fastening consists of a powerful spring like a Bourdon gauge tube which can only be straightened to release the catch by admitting fluid under pressure.

Means for lighting the lamp without opening it were also discussed, as these are generally the miner's chief reasons for opening his lamp. Besides several other igniting substances for this purpose, sodium amalgam was said to have given promise.

**Thornburry Safety Lamp.**—According to a report by Sir F. Abel and Professor Dewar,* the Thornburry safety lamp has been tested in currents of explosive gas up to 50 feet a second. In all cases the lamp was extinguished in a very few seconds after the current was established, and the gas was never seen to burn inside the lamp. It maintains a steady light of 1 to 1½ candle-power. Mr. C. E. Rhodes has tested the lamp underground, and states that it is unlikely to ignite gas under any condition. The fuel is mineral oil of high flashing point and is burned from a wick under a cone like those used in ordinary paraffin lamps. The base contains the oil reservoir, and is connected by columns to an upper ring, to which the chimney and case are attached. Two concentric glass cylinders are fixed between the ring and base. The air supply is admitted through a gauze cylinder and passes between the glasses and through a gauze ring into the cone, where it supplies the flame. The cone causes a sharp draught and steadies the flame. The products of combustion escape through holes at the top of the case after passing through a gauze cone. The lamp is locked by a bolt and pin with a bayonet joint having a part which can be riveted to the oil reservoir.

**The Use of Electricity for Blasting.**—J. Libert † describes the various electric arrangements used in shot-firing. He classifies them

* *Engineering*, vol. xlviii. pp. 552 and 572.
† *Revue Universelle des Mines*, vol. vii. pp. 147–174, with illustrations.

under two main heads—firstly, those which produce the detonation by a spark, and, secondly, those in which it is effected by a wire raised to a red heat. He then describes the various arrangements that have been suggested under a number of subdivisions. The powder used to start the explosion in the spark methods has a very variable composition, and its conductivity for electricity is a matter of very great import, owing to the breaking of the current to produce the spark. If it conducts too readily no spark will be produced, and similarly the same effect will result from the powder not possessing this property in a sufficient degree. Its composition must vary with the distance the spark has to travel from one point of the wire to the other. The author also devotes attention to the machines used in generating the current of electricity, to the conductors, and to the arrangement of the circuits. He next passes to a consideration of the economic side of the question, and shows that electric blasting possesses one important advantage the money value of which it is not possible to calculate, that of being able to blast at several places simultaneously with the accompanying saving of time. The author believes that there is a great future for electricity as a blasting agent.

**Explosives.**—At the Mining and Metallurgical Congress held in Paris, M. Mallard, the Secretary of the Explosives Commission, stated that, in the six years following 1881, 34 lives were lost through accidents caused by defective lamps, and 194 in explosions resulting from shot-firing. The number of accidents per 1000 men employed has actually increased, and this is due to the increasing depths of the workings. High explosives are much less dangerous than powder, as the latter practically deflagrates, whilst the ignition of explosives is more nearly instantaneous, so that there is less chance for the ignition of fire-damp. The mines at Marihaye and Seraing in Belgium, and Blanzy in France, have abandoned the use of explosives, but evidence has been produced to show that the substitution of the *bosseyeuse* (coal-getter) leads to increased cost of output. The action of the explosive depends on two factors—the temperature of the explosion and the time during which this temperature is maintained. Accordingly, as much as possible of the energy of the explosion should be expended in doing work, so that it is not used to raise the temperature of the products of combustion. A classification of explosives is made, depending on the nature of the constituents. The Commission has examined a large number of substances incapable of igniting fire-damp under

experimental conditions. Of these, two passed through actual working tests in mines with success. One of these is a mixture of dinitrobenzene, or gun-cotton, with nitrate of ammonium; the other a mixture of nitro-glycerine and nitrate of ammonium. Some 13 tons of these substances have been used in the Anzin collieries. The necessity of tamping was insisted on by several speakers, and also the danger of tamping with coal.

The explosives regulations for the city of New York have recently been published,* and contain directions with regard to blasting, using, and thawing frozen cartridges, tamping, missed blasts, &c.

Some historical notes on explosives and blasting have been given by Mr. O. Guttmann.† The origin of gunpowder, according to the researches of the author, cannot definitely be ascribed to any one man, but appears to be a gradual evolution. Blasting also arose in a similar manner.

Petragite, an explosive invented by M. Doutrelepont, is shown by Muck ‡ to contain 12 per cent. of nitro-glycerine. It consists of about equal parts of nitrated molasses and wood meal, containing 56·4 per cent. of potassium nitrate. Experiments made at the Alstaden Colliery gave very good results. The explosive is not subject to decomposition; it is regular in composition, and the explosion is not accompanied by flame. Its manufacture is without danger, and it is not affected by concussion. It has about the same blasting power as powder, so that large charges are necessary.

C. Nicolaysen § states that at Christiania several fires have recently been found to be due to the spontaneous combustion of the explosive romite. The components of this explosive are sent from the manufactory in two separate packages, which are mixed immediately before use; one consists of potassium chlorate, and the other of naphthalene and ammonium nitrate. Examination has now shown that this latter mixture, when slightly heated, readily explodes, in consequence of which the Norwegian Government has ordered that no mixed romite shall be carried on the State railways, and that even the unmixed materials shall only be forwarded by powder trains.

A committee consisting of Dr. N. Hannah, Dr. C. J. Mouncey, and Mr. H. B. Dixon, has presented a report ‖ on the results of a series of

* *The Engineering and Mining Journal*, vol. xlvii. pp. 565, 566.

† Paper read before the Royal Cornwall Polytechnic Society, *Engineering*, vol. xlviii. p. 560.

‡ *Glückauf*, vol. xxv. p. 433.

§ *Chemiker Zeitung*, vol. xiii. p. 1158.

‖ *Iron*, vol. xxxiii. pp. 536–537.

experiments with roburite at the Park Lane collieries and elsewhere. They conclude that there are undoubted cases of nitro-benzene poisoning arising from improper manipulation of the cartridges, that roburite undergoes complete combustion if properly confined, but that there is a chance of incomplete combustion if the explosive does not meet sufficient resistance, that carbonic oxide is produced by the action of the heated gases on the coal, and that this carbonic oxide may be the cause of headache complained of. The committee recommends that the entire manipulation of the cartridges should be entrusted to shot-firers properly instructed in their use; that the effective tamping of the cartridges should be insisted on; that the fumes should be removed as quickly as possible by advancing the brattice cloth, and that they should be speedily mixed with large volumes of air.

A further committee was appointed by the Lancashire Miners' Federation to deal with the above report.* It was concluded that the report showed the extreme danger of using roburite, and that, therefore, its use should be discontinued.

Experiments recently made with carbo-dynamite show that it is superior to ordinary dynamite in the work performed, besides which no noxious fumes were observed. It was concluded that No. 1 carbo-dynamite was equal to blasting gelatine, and No. 2 quality to No. 1 ordinary dynamite. The explosive can be fired successfully after soaking in water.†

The subject of explosives generally is fully treated by Mr. P. F. Nursey ‡ and by Mr. C. N. Hake.§

Experiments have been made with tonite at Melling, near Ormskirk, to show that Trench's fire-preventing compound prevented flame and explosion.||

In some experiments made with carbonite at the Nunnery Colliery, one charge of six ounces brought down twelve tons of coal, the cost of the explosive being 4½d., as compared with 3d. for powder, but, on the other hand, no flame was observed, and the charge of carbonite was rather too heavy.¶

Favierite consists mainly of ammonium-nitrate and mononitro-naphthalene, but sometimes dinitro-benzene or other nitro-hydrocarbon is

* *Iron*, vol. xxxiv. p. 75.

† *Ibid.*, pp. 25–26.

‡ Paper read before the Society of Engineers.

§ *The Journal of the Society of Chemical Industry*, vol. viii. pp. 518–525.

|| *The Iron and Coal Trades Review*, vol. xxxix. p. 233.

¶ *Ibid.*, p. 427.

used instead of the nitro-naphthalene. At Haeren lez Vilvorde cartridges of this explosive are made which have the diameters of 0·98 inch, 1·18 inch, and 1·38 inch, the respective weights being 0·110 lb., 0·165 lb., and 0·231 lb. These cartridges are submitted to considerable pressure to enable them to resist moisture, but when strongly compressed the explosive is difficult to fire, and to avoid this difficulty the inventor fills a hollow in the compressed cartridge with material which may be more readily exploded. The form and composition of the cartridge, however, vary greatly. The composition employed at these works is usually the following :—

| | Per cent. |
|---|---|
| Mononitro-naphthalene ($C_{10}H_7NO_2$) . . . . . . . | 9 |
| Ammonium nitrate ($NH_4NO_3$) . . . . . . . . | 91 |
| | 100 |

This composition is such that the ammonium nitrate suffices in itself to complete the combustion of the mononitro-naphthalene, as will be seen from the following reaction :—

$$2\ C_{10}H_7NO_2 + 43\ NH_4NO_3 = 20\ CO_2 + 44\ N_2 + 93\ H_2O.$$

Ten parts by weight of the ammonium nitrate are thus required for every one part of the other constituent. The following are other mixtures employed :—

| | II. | III. | IV. |
|---|---|---|---|
| Mononitro-naphthalene . | 7·0 | 10·0 | 10·0 |
| Ammonium nitrate . . | 93·0 | 70·0 | 45·0 |
| Sodium nitrate . . . | 0·0 | 20·0 | 45·0 |
| | 100·0 | 100·0 | 100·0 |

The favierite cartridges possess the remarkable property that, whilst they are not exploded by shock, a capsule can only explode them when they are placed in a very circumscribed space. Cold is without influence; they burn in an open fire without danger, and the ignition ceases directly the flame is removed.*

* *Revue Universelle des Mines*, vol. v. No. 1.

The following table shows the relative degree of safety for colliery purposes of the more important explosives in ordinary use:*—

| | Fires regularly. | Fires occasionally. | Never fires. |
|---|---|---|---|
| 0·66 lb. explosive; clay tamping; coal-dust present but no gas. | Ordinary powder<br>Carbo-dynamite<br>Blasting gelatine | Gelatine-dynamite<br>Kieselguhr-dynamite<br>Roburite | Securite<br>Favierite<br>Carbonite<br>Fire-damp dynamite<br>Ammonia-dynamite<br>Water cartridges |
| 0·66 lb. explosive; clay tamping; both coal-dust and gas present. | Ordinary powder<br>Carbo-dynamite<br>Blasting gelatine | Gelatine-dynamite<br>Kieselguhr-dynamite<br>Roburite | Securite<br>Favierite<br>Carbonite<br>Fire-damp dynamite<br>Ammonia-dynamite<br>Water cartridges |
| 0·22 lb. explosive; no tamping; coal-dust present, but no gas. | Ordinary powder<br>Carbo-dynamite<br>Blasting gelatine<br>Gelatine-dynamite<br>Kieselguhr-dynamite | Roburite | Securite<br>Favierite<br>Carbonite<br>Fire-damp dynamite<br>Ammonia-dynamite<br>Water cartridges |
| 0·66 lb. explosive; no tamping; coal-dust present, but no gas. | Ordinary powder<br>Carbo-dynamite<br>Blasting gelatine<br>Gelatine-dynamite<br>Kieselguhr-dynamite<br>Roburite<br>Securite | Fire-damp dynamite | Favierite<br>Carbonite<br>Ammonia-dynamite<br>Water cartridges |
| 0·66 lb. explosive; no tamping; both coal-dust and gas present. | Ordinary powder<br>Carbo-dynamite<br>Blasting gelatine<br>Gelatine-dynamite<br>Kieselguhr-dynamite<br>Roburite<br>Securite | Fire-damp dynamite<br>Ammonia-dynamite | Favierite<br>Carbonite<br>Water cartridges |

**Coal Transfer.**—The usual method of transferring coal from the trucks to barges on the Ohio appears to be by baskets lowered vertically. In some cases, the truck itself is lowered bodily. Whatever arrangement is adopted, all kinds of trucks must be accommodated, the coal must be handled gently, and should preferably be carried, and not allowed to grind over itself and the sides and bottom of the shoot. The barge should be loaded uniformly to avoid strains and leakage.

* *Zeitschrift für das Berg- Hütten und Salinenwesen*, vol. xxxvii. Table C.

The cost must be kept as low as possible and the capacity unlimited when gravity is used, and lastly, the structure should be its own protection against high water.

A coal transfer, to comply with these requirements, is described by Mr. W. N. Page.* It is erected on the Kanawha for the Mt. Carbon Company, and has been in use for several months. It is a simple application of a flexible steel belt, 4 feet wide, with 6-inch flanges, and 95 feet from centre to centre of sprocket shafts. There are three chains with a segment of the belt bolted to each alternate link. The chains are made of ½ by 2-inch steel bars, with ¾-inch pins, 6 inches from centres; the segments are No. 12 gauge soft steel and lap ¾-inch. The chains run on small flanged rollers, placed every 4 feet on 6-inch girders. Each girder is 24 feet long; the joints are made by fish plates, and are supported by differential blocks. The empty part of the belt is returned on three pulleys. The inclination is adjusted from one end.

The hopper under the waggon holds less than a ton, so that, practically, the coal is drawn direct from the truck. The shoot for delivering the coal into the barge is built of steel, and discharges at the sides first; the hinged apron can then be folded back so as to load the centre.

The belt is rotated by a small winch, and is geared to 100 feet per minute, so that it will empty a 12-ton truck in two minutes, or at the rate of 360 tons per hour. The belt has never been worked by gravity alone, but this probably could be done between the angles of 10° and 30°, and this would be enough margin to cover considerable variations in the height of the river.

The cost of the transfer in working order was £103. Two men are required at a cost of 14s. 5d., but to this must be added the expense of emptying the trucks. With self-emptying trucks 4000 tons could be transferred in twelve hours at a cost of about 1d. per ton. Screens could easily be added to the arrangement described.

Lieut. T. V. Greet,† Mr. J. Rigg, and others have treated of the subject of handling coal as far as it relates to the coaling of steamers. The methods used are three in number. In the first system, the loaded trucks are raised to a suitable elevation, and their contents tipped into a shoot. The second system includes continuous elevators similar to those used for grain, and the third division includes elevators

* *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 454–459.
† *The Journal of the Royal United Service Institution*, vol. xxxiii. pp. 67–79.

fixed in the coaling vessel. As an illustration of the first system, a plant recently erected in Venezuela was described. A steel framework, 65 feet high, and travelling on rails, is used for raising the truck, which is then tipped and returned in three minutes. Drawings are given of floating elevators, &c.

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## VIII.—*COAL-WASHING.*

**Banking-out and Screening Plant at East Hetton Colliery.**—According to Mr. S. Tate,* it was decided to reconstruct the pit heap and screening plant of the upcast shaft at East Hetton Colliery, so that the greatest amount of mechanical power could be utilised. In the scheme adopted, after the full tub has been emptied, it runs by force of gravitation to a point where it is taken to the other side of the shaft by mechanical power. The coals are tipped into a jigging screen where they are sorted into three kinds—(1) best, (2) nuts, and (3) peas and duff. The best coals are carried along a travelling belt, and the stones, &c., picked out by boys placed along each side. The nut coals are delivered out at the side of the jigging screen on to a belt running parallel with the best coal belt, but at a different angle. After the stones, &c., are picked out, the coals are delivered over a set of screen bars or gauzes, by which the treble and double nuts are separated into their respective waggons. The peas and duff coals drop out at the bottom of the jigging screen on to a smaller belt running in a direction contrary to the other belts, and which carries the coals to an ordinary "Beeswing" elevator. In this manner, the coals are much better cleaned, and at a very much less cost than was formerly the case. The advantages derived from this system of banking-out and screening may be summarised as follows:—1. Cheapness of labour cost, consequent on utilising mechanical power. 2. Cheaper class of labour employed. 3. Coals are better cleaned, and with less breakage.

Illustrations and description of the elaborate plant for handling and washing coal, belonging to the Commentry Fouchamboult Company, are given in *Le Génie Civil.*

**Mechanical Slate Picker.**—A very simple form of apparatus for separating slate from coal has recently been exhibited. A shoot with

* *Transactions of the North of England Institute of Mining Engineers,* October 12, 1889.

a sheet iron bottom is placed beneath the screens, and is ridged transversely at intervals. Just beyond the ridge is a transverse cloth, 6 to 8 inches wide, and adjustable in width by a sliding plate. The coal and slate slide down the shoot; the slate, as it is heavier and rougher than the coal, is somewhat arrested by the ridge, and so falls through the opening beyond, but the coal, being lighter and more glassy, gathers enough impetus to jump over the opening and pass to the bunkers.*

**Weight per Cubic Foot of Broken Anthracite.**—Experiments have been made under the direction of Mr. J. W. Bowden † to determine the actual weight per cubic foot of anthracite broken to different sizes. Süsquehanna Coal Company's anthracite was used in proportions and with results as follows:—

| | | | Lbs. |
|---|---|---|---|
| 45 | per cent. | Mill's seam, average weight per cubic foot, | 90·46 |
| 15 | ,, | Twin ,, ,, ,, ,, | 92·20 |
| 25 | ,, | Ross ,, ,, ,, ,, | 93·00 |
| 15 | ,, | Buck Mountain ,, ,, ,, | 94·75 |
| 100 | ,, | mixed coal ,, ,, ,, | 92·00 |

Space filled as loaded at breaker without settling. Add 5 per cent. for packed spaces or large heaps.

| Size. | Size of Mesh in Inches. | | Weight per Cubic Foot. | Cubic Foot from 1 Cubic Foot Solid. |
|---|---|---|---|---|
| | Over. | Through. | Lbs. | |
| Lump . . . . | $4\frac{1}{2}$–9 | ... | 57 | 1·614 |
| Broken . . . . | $2\frac{3}{8}$–$2\frac{7}{8}$ | $3\frac{1}{4}$–$4\frac{1}{2}$ | 53 | 1·755 |
| Egg . . . . | $1\frac{3}{4}$–$2\frac{1}{4}$ | $2\frac{3}{8}$–$2\frac{7}{8}$ | 52 | 1·769 |
| Large stove . . . | $1\frac{1}{4}$–$1\frac{7}{8}$ | $1\frac{3}{4}$–$2\frac{1}{4}$ | $51\frac{1}{2}$ | 1·787 |
| Small stove . . . | 1 –$1\frac{1}{4}$ | $1\frac{1}{4}$–$1\frac{1}{2}$ | $51\frac{1}{4}$ | 1·795 |
| Chestnut . . . | $\frac{5}{8}$– $\frac{3}{4}$ | 1 –$1\frac{1}{4}$ | 51 | 1·804 |
| Pea . . . . | $\frac{3}{8}$– $\frac{5}{8}$ | $\frac{5}{8}$– $\frac{7}{8}$ | $50\frac{3}{4}$ | 1·813 |
| No. 1 buckwheat . . | $\frac{3}{16}$– $\frac{3}{8}$ | $\frac{3}{8}$– $\frac{5}{8}$ | $50\frac{3}{4}$ | 1·813 |
| No. 2 buckwheat . . | ... | $\frac{3}{16}$– $\frac{3}{8}$ | $50\frac{3}{4}$ | 1·813 |

* *The Canadian Mining Review*, vol. viii. p. 52.
† *The Engineering and Mining Journal*, vol. xlvii. pp. 496–497.

# PRODUCTION OF PIG IRON.

## CONTENTS.



## I.—*BLAST FURNACE PRACTICE.*

**Result of Blast Furnace Practice with Lime as Flux.**—Sir L. Bell has given the maximum ratio of carbonic oxide to carbonic anhydride in gases escaping from the blast furnace as one to two by volume or three to four by weight. The maximum efficiency of the furnace has been calculated by M. Gruner with these data. Probably these figures are correct under certain conditions, but Mr. C. Cochrane* shows that unrecorded conditions affect this result. The two leading features are the combustion of carbon to carbonic oxide at the tuyeres, and the reaction of this gas on oxide of iron as shown by the formula $Fe_2O_3 + 3CO = Fe_2 + 3CO_2$. Assuming that 15 cwt. of pure carbon produces 20 cwt. of pure iron, there is 35 cwt. of carbonic oxide produced at the tuyeres, and, according to the above formula, 15 cwt. of carbonic oxide is required to reduce the iron, giving 23·57 cwt. of carbonic anhydride. The ratio of carbonic anhydride to carbonic oxide thus becomes 23·57 to 20·00 or 1·18 to 1. As a matter of fact Sir Lowthian Bell's ratio of 0·75 has not been attained in Cleveland furnaces, but the author proposes to show that the reason is to be found in the reaction of red-hot coke on carbonic anhydride.

In the blast furnace red-hot coke will reduce the carbonic anhydride. One unit of carbonic anhydride by reduction to carbonic oxide requires 5607 heat units or the combustion of $5607 \div 2473 = 2·26$ units of carbon; one unit has disappeared in the process, so 1·26 unit

* *Proceedings of the Institution of Mechanical Engineers.*

extra has to be burnt at the tuyeres, and there is a total loss of efficiency of 2·26 units. When limestone is employed as a flux, it acts as one source of carbonic anhydride, and the reduction of iron oxide acts as the other. The reduction of the ore should take place at a point above that where the temperature is great enough to decompose the flux. If the ore plunges down to the red-hot region before decomposition so that the resulting carbonic anhydride is all decomposed again by coke, there may be an increased consumption of 13·65 cwt. of carbon per ton of pig iron at the tuyeres. In order to economise in this direction, the furnaces at Middlesbrough were increased in size to give greater time for reduction. Analyses of the gases from these high furnaces show slightly more carbonic anhydride than can be accounted for by the reduction of iron, and this must proceed from the limestone. The amount, however, is small, and does not affect the main question.

An elaborate comparison is then made by the author between the results obtained from a furnace working under two different conditions.

| | Working on Limestone. | Working on Lime. |
|---|---|---|
| Ratio of $CO_2$ to CO by weight | 0·473 | 0·535 |
| Temperature of blast | 807° C. | 765° C. |
| Temperature of escaping gases | 327° C. | 301° C. |
| Coke consumed per ton of pig iron | 23·28 cwt. | 19·49 cwt. |
| Limestone consumed per ton of pig iron | 13·18 „ | 12·28 „ |
| Total weight of dry air required per ton of pig iron | 114·05 „ | 87·69 „ |
| Total weight of dry gases escaping | 146·23 „ | 113·10 „ |
| Consumption of calcined ironstone per ton of iron | 50·13 „ | 50·00 „ |
| Make of pig iron per month | 2141 tons | 2453 tons |
| Quality of pig iron. No. | 3·25 | 3·31 |
| Blast, pressure per square inch at tuyeres | 3·87 lbs. | 3·73 lbs. |
| Area of tuyeres in square inches | 142 | 142 |

The economy in pure carbon in the coke is 21·19 − 17·44 = 3·75 cwt. per ton of pig iron, whereas by calculation on the lines indicated above the saving should have been 2·94 cwt., according to the composition of the escaping gases. The ratio of carbonic anhydride to carbonic oxide has not been raised so much as was hoped, and in this the use of lime has failed to accomplish all that was desired, for the weight of carbonic anhydride of reduction has been diminished. The causes of this disappointment are twofold. When limestone is used its carbonic anhydride is reduced to oxide, and so the activity of the

reducing zone is increased and prolonged into a cooler region. At the same time this cooler region is prolonged downwards by the unburning of carbonic anhydride, so the employment of limestone is not an unmixed evil. Secondly, when lime is used the reducing zone is reduced in depth, and a less weight of gas passes over the ore, so that it is not so well reduced in the proper place; but, on the other hand, there is a large economy by reason of the less volume of blast used.

Finally, the author calls attention to two mistakes made by him in 1883.* The first was that the decomposition of carbonic anhydride necessitated a loss of 3·26 instead of 2·26 units of carbon; and, secondly, no allowance was made for melting the iron.

In the discussion that ensued, Sir Lowthian Bell stated that he had found nothing which induced him to go back from the limit he had assigned for the ratio of carbonic anhydride to carbonic oxide, namely, one to two by volume. When equal volumes of carbonic anhydride and oxide are passed over ferric oxide, the oxygen is detached till 33 per cent. is separated, and then no more is taken up. From this he inferred that the ratio must be one to two. Another experiment is to pass the same mixture over spongy iron, which will absorb oxygen until it is converted into ferrous oxide, when the process will stop. It is admitted that the action between the gases is influenced by temperature. At the temperature of the escaping gases it is possible to obtain a ratio of one to two instead of equal volumes, and the author has passed these gases over iron ore for 96 hours with a diminution of only 5 per cent. of oxygen. The difficulty is to get the due proportion of the two gases. With regard to the use of lime, the heat expended in burning the limestone has to be taken into account, and further, caustic lime absorbs carbonic anhydride in the upper part of the furnace. Admitting Mr. Cochrane's figures, it is impossible to save more than 2 cwt. of coke. The question of dissociation was also referred to, with its bearing on the sources of appropriation of heat, a point not sufficiently taken into consideration. Instead of 2·67 cwt. of coke required for melting the pig iron, only 1·46 cwt. is required. The division should be carbon to carbonic oxide per unit of coke, 2040 calories; carbonic oxide to anhydride, 1460 calories; heat in blast, 730 calories; total, 4230 calories—this divided into 6600 gives 1·46 cwt.

Mr. W. Richards has used lime in some furnaces at Eston, and limestone in others. With lime the furnaces worked better, but with no appreciable economy in fuel. The average of five furnaces for a fort-

* *Journal of the Iron and Steel Institute*, 1883, p. 291.

night showed an advantage of 50 tons with lime, but it took 1 ton of small coal to produce 30 tons of lime, so that the operation did not pay. Further, the furnaces worked very well all the time, despite the variations in the proportions of carbonic oxide and anhydride.

Mr. Martin and Mr. David Evans were of opinion that the use of lime in low furnaces might be beneficial. The latter mentioned a furnace in South Wales, 45 feet high, using lime with a larger output and economy of fuel.

Mr. Cochrane agreed that disadvantages did exist in the use of lime. His figures, however, showed a reduction from 23·28 to 19·49 cwt. of coke in actual work, though he could not explain them. He was of opinion that perfect reduction was possible in the cooler parts of the furnace when limestone was used, but lime was at considerable disadvantage in that a much larger proportion of ore was reduced in the red-hot zone. If this effect could be reduced, his statements in 1883 would be nearer the truth.

**Unreduced Ore passing through a Blast Furnace.**—Mr. E. S. Cook exhibited, at the recent meeting at Milwaukee of the United States Association of Charcoal Iron Workers, some specimens of partly reduced iron ore which had been taken from the tuyeres of the Warwick Blast Furnace, Pottstown, Pennsylvania. Some of the specimens were only partially reduced on the surface, and others were encased by a covering of malleable iron. The ore was from the Republic Mine, in the Lake Superior District. The furnace in which this partial reduction was observed had been running on one lining for about three and a half years, and had made during that period about 108,000 tons of iron. During the year ending February 1, 1889, the furnace worked well, making from 650 to 710 tons of iron a week, although the furnace is but 55½ feet high by 15½ feet diameter at the boshes. In February the furnace began to work irregularly, and the output fell off to 550 or 600 tons a week. On March 1 there was a fall of carbonaceous and other matter that had taken the place of the brickwork of the boshes, which had melted away during the course of the campaign. The result of this fall of scaffolding was that the temperature of the crucible became so reduced that it was with difficulty the tuyeres were kept open. The iron-notch and cinder-notch became closed. Several tuyeres were closed at the nose by plugs of the spongy iron, followed by the partial fusion of unreduced ore. The other tuyeres were kept open and the slag made was discharged from

the furnace through the tuyere slagging valves attached to the belly-pipes. These valves are operated by air-cylinders and are opened and closed with the engine running, and the slag can be discharged without any risk or loss of time. After about twenty-four hours of close attention and hard work, the furnace was again in fair working order. An examination showed that the brickwork on the west side of the furnace about the top of the boshes was only 2 to 3 inches thick, whilst on the east side it was 9 to 10 inches. This was determined by drilling holes at intervals through the furnace walls. In order to fill up and restore the bosh to something approximating suitable proportions, it was decided to run the furnace on silver-grey iron, in hopes that a graphitic bosh could be formed. It was while this effort was being made that the samples of unreduced ore were obtained from the tuyeres on the east side. It was observed that the tuyeres on the west side worked much better and brighter than those on the east side. The temperature was experimentally determined by driving bars of wrought iron into the centre of the furnace through the plug-holes of the several tuyeres. On the west side the bars became white-hot and melted off before they could be drawn out, whilst on the east side similar bars were bright red at the points, and only dull red for the greater part of their length. About the same time the tuyeres on the east side were rapidly cut, exploding with reports similar to pistol shots. As these tuyeres were removed the stock in front of them was taken out and preserved. It was from this stock that the specimens of unreduced ore were selected. At this time the stock was passing through the furnace in about sixteen to eighteen hours, and the iron made was chiefly No. 1. The slag was uniform and hot, and the furnace was working fairly regularly, but not with the usual fuel economy or average yield of iron. Owing to the shape of the furnace being oblong, instead of circular, it was supposed that a much larger volume of gas ascended on the west side than on the east. The gas currents thus established thoroughly reduced the ore on that side, but were deficient in quantity on the east side, and thus the ore on this side descended without being properly acted upon, and reached the tuyeres and crucible unreduced. The presence of unreduced ore naturally made that side of the furnace work cold, and this again facilitated still further arrivals of unreduced ore in the crucible. The frequent loss of tuyeres was due to the formation of pockets under the tuyeres, which filled with iron as it was melted, and this iron coming into contact with the bronze of the tuyeres produced the explosions. In order to

rect this condition of affairs a long tuyere was placed on the west e, projecting 20 inches or more beyond the tuyere breast, and small zzles of 3 inches in diameter, instead of 5 inches, were placed on the t-side tuyeres. This had the desired effect.

**Blast Furnace Lines.**—In support of a statement in a previous per that the furnace shaft should be as narrow as possible, Mr. E. alsh * draws special attention to two furnaces—the Union, No. 2, at icago, and the Treibach, No. 3, at Treibach, Austria. Details of eral other furnaces are also given. The fuel of the first-mentioned nace is coke; charcoal is used in the second. The dimensions, &c., respectively as follows:—Capacity, 6676 and 1872 cubic feet; height, feet 4 inches and 49 feet 8 inches; diameter of hearth, 8½ and 4½ t; diameter of bosh, 14 and 10⅓ feet; diameter of throat, 9½ feet l 3 feet 4½ inches; daily product, 114·3 and 24 tons; time in fure, 19 and 10 hours; fuel per ton of metal, 1697 and 1365 lbs.

**French Blast Furnace Practice.**—At the Micheville blast fures a white forge iron is produced which has the following comition:—

| Carbon. | Silicon. | Sulphur. | Phosphorus. |
|---|---|---|---|
| 2·75 | 0·30–0·60 | 0·25–0·50 | 1·60–2·00 |

The slag produced contains:—

| Silica. | Alumina. | Lime. | Iron. |
|---|---|---|---|
| 36·60 | 17·85 | 38·44 | 2·60 |

From 1·25 to 1·35 ton of coke is required for each ton of grey pig n made, for forge iron the quantity is 1·0 to 1·05 ton.

The Cie. des Forges de Champagne possesses four blast furnaces ich are provided with ten Cowper stoves. They are situated at rnaval St. Dizier, and smelt the ore occurring at Pont Varin Wassy, analysis of which shows:—

| | Unwashed Ore. | Washed Ore. |
|---|---|---|
| | Per cent. | Per cent. |
| Silica | 15·00 | 12·70 |
| Alumina | 12·10 | 7·17 |
| Ferric oxide | 57·40 | 64·33 |
| Manganese oxide | 0·80 | 0·86 |
| Lime | 0·30 | 0·25 |
| Phosphoric anhydride | 0·62 | 0·55 |
| Sulphuric anhydride | 0·12 | 0·08 |
| Loss on ignition | 13·50 | 13·90 |

* *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp 754–757.

The pig iron made from these ores has the following composition :—

| | Foundry Iron. | Grey Forge Iron. | White Forge Iron. |
|---|---|---|---|
| | Per cent. | Per cent. | Per cent. |
| Carbon | 4·00–4·50 | 3·50–4·00 | 3·00–3·50 |
| Silicon | 2·50–3·00 | 0·50–0·95 | 0·20–0·60 |
| Sulphur | trace–0·05 | 0·03–0·07 | 0·04–0·08 |
| Phosphorus | 0·40–0·80 | 0·40–0·80 | 0·40–0·85 |
| Manganese | 0·60–0·90 | 1·00–1·50 | 0·80–1·00 |

The slag produced has the following composition :—

| | Foundry Iron. | Grey Forge Iron. | White Forge Iron. |
|---|---|---|---|
| | Per cent. | Per cent. | Per cent. |
| Silica | 31·50–32·00 | 29·50–30·00 | 29·50–30·00 |
| Alumina | 23·50–24·00 | 21·50–22·00 | 22·50–23·00 |
| Lime | 43·50–44·00 | 47·50–48·00 | 46·50–47·00 |

By the addition of manganese ores from Laurium in Greece, or Romanêche, France, the following metal is produced :—

| Carbon. | Silicon. | Sulphur. | Phosphorus. | Manganese. |
|---|---|---|---|---|
| 3·50–4·00 | 0·10–0·35 | trace–0·03 | 0·40–0·75 | 4·50–5·00 |

The slag then produced contains :—

| Silica. | Alumina. | Lime. |
|---|---|---|
| 27·00–27·50 | 21·00–21·50 | 51·00–51·50 |

About 3 millions of slag bricks are produced annually at this works.

At the Firminy Steelworks there is one blast furnace with a daily production of about 90 tons. The following are analyses of ores smelted :—

| Locality. | $SiO_2$. | $Al_2O_3$. | CaO. | Fe. | Mn. | P. | S. |
|---|---|---|---|---|---|---|---|
| | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. |
| Spiliazeza, Greece | 2·0 | 0·0 | 2·2 | 35·0 | 19·5 | 0·03 | 0·02 |
| Mokta el Hadid, Algiers | 6·0 | 1·0 | 1·0 | 58·5 | 1·5 | 0·03 | 0·02 |
| Elba | 12·0 | 0·5 | 1·0 | 50·0 | 0·0 | 0·03 | 0·03 |

The following are analyses of the pig iron and spiegeleisen produced :—

| | Carbon. | Silicon. | Manganese. | Phosphorus. | Sulphur. |
|---|---|---|---|---|---|
| | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. |
| Foundry iron . . . . | 3·40 | 3·20 | 0·10 | 0·07 | 0·02 |
| White forge iron . . | 3·20 | 0·40 | 1·02 | 0·07 | 0·07 |
| Silicon-spiegeleisen . | 1·42 | 17·00 | 18·09 | 0·085 | trace |
| Spiegeleisen. . . . | 4·00 | 4·50 | 15·00 | 0·07 | 0·01 |

At the St. Louis Works, Marseilles, metals of the follow composition are produced :—

| | Fe. | Mn. | Total Carbon. | Graphite. | Si. | S. | P. | Cu. |
|---|---|---|---|---|---|---|---|---|
| | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. | Per cent. |
| Spiegeleisen. . | 65·80 | 27·41 | 6·00 | 0·28 | 0·23 | 0·009 | 0·062 | 0·019 |
| Ferromanganese | 47·14 | 46·19 | 5·93 | 0·14 | 0·14 | 0·005 | 0·095 | 0·024 |
| Ferromanganese | 6·23 | 85·40 | 7·10 | 0·56 | 0·47 | trace | 0·168 | 0·060 |
| Ferrosilicon. . | 82·60 | 2·50 | 2·10 | 2·10 | 12·60 | 0·054 | 0·088 | trace |

Both foundry and forge pig iron are also made at this works.*

**French Blast Furnaces.**—The following are the dimensions of two blast furnaces erected at Micheville, France :—

| | I. | | II. | |
|---|---|---|---|---|
| | Feet. | Inches. | Feet. | Inches. |
| Height . . . . . . . | 67 | 7 | 67 | 7 |
| Diameter at crucible. . . | 6 | 7 | 7 | 6 |
| Diameter at boshes . . . | 21 | 4 | 22 | 2 |
| Diameter at throat . . . | 17 | 3 | 18 | 1 |
| Capacity, cubic feet . . . | 15,892 | | 16,775 | |

No. 1 furnace was put into blast in 1878, foundry iron being made, the outturn being from 80 to 90 tons. White iron was afterwards made in place of the foundry iron, and the production increased to 120 tons. The blast is heated by six Whitwell stoves, each 49 feet 2 inches in height, but these are now being replaced by Cowper stoves.†

* *Stahl und Eisen*, vol. ix. p. 858.
† *Ibid.*, p. 856.

**The Blast Furnaces at the Isbergues Steelworks, France.**—F. Laur* states that the main dimensions of the two blast furnaces erected at these works are as follows:—

| | Feet. | Inches. |
|---|---|---|
| Height | 65 | 7 |
| Diameter at the boshes | 19 | 8 |
| Diameter at the throat | 14 | 8 |
| Diameter at the crucible | 7 | 4 |

The capacity is about 12,360 cubic feet.

Somorrostro ore is alone used, the percentage of sulphur not exceeding 0·04, and that of phosphorus 0·05. The daily production of the furnaces is about 260 tons, with a consumption of 495 tons of ore, 95 tons of limestone, and 265 tons of coke. The blast is heated in twelve Whitwell stoves to a temperature of 750°, the pressure being usually about 9½ inches, reaching occasionally 11 inches.

**Russian Ironworks.**—Professor Time, of the St. Petersburg Mining Institute, has prepared an elaborate report on the present condition of the metallurgical and mining industries of the Don coalfield. This has been translated from the Russian by Mr. G. Kamensky.†

The author first describes the oldest of the South Russian ironworks—those of Mr. Hughes. They are typical English works, with two blast furnaces. It is now proposed to build a third, capable of yielding 160 tons per day. The life of the old coke furnaces having a yield of 25 to 30 tons per day often exceeded nine years, or about 110,000 tons during the whole period. Under present conditions at Hughes' works a furnace is capable of yielding 100,000 tons during its four years' life. Mr. Hughes is of the opinion that a shorter life with a corresponding increase in production is still more profitable, and that 150,000 tons of iron may be smelted in two or three years with great advantage.

The Hughes works possess both a puddling and a steel-making department. The former consists of eight open-hearth furnaces and a three-high rolling mill. The yearly production of rails is nearly 30,000 tons. The open-hearth process takes twelve hours. The furnace charge is composed of 10 tons of pig iron, 5 tons scrap iron, ½ ton spiegeleisen, and a small quantity of Krivorogesky iron ore. The metal is run into a cast iron mould. The ingots have a section of 14 inches square at the wide end, and 12 inches at the narrow end. Their

* *L'Écho des Mines* vol. xiv., No. 41, p. 5.

† *The Colliery Guardian*, vol. lvii. p. 876; vol. lviii. pp. 24, 83, 132, 241.

weight varies from 1 ton to 1¼ ton. Each ingot makes four rails. One ton of rails requires the consumption of ½ ton of coal in the open-hearth furnaces, and ¾ ton for reheating and working the rolling mills.

The number of men employed at the works and in the mines is 4000. The amount paid in wages varies from £15,000 to £18,000 per month. The production of the Hughes ironworks during the year 1888 amounted to 53,704 tons of pig iron, 26,877 tons of steel rails, 4224 tons of chairs, fish plates, &c., and 4750 tons of manufactured iron. Of coal, 263,730 tons were raised, and 67,708 tons of coke were produced. The following are analyses of the material used :—

| | Belokrisensky. | Ingouletzsky. | Terenashinsky. | Lifmansky. |
|---|---|---|---|---|
| $Fe_2O_3$ . . . | 92·14 | 91·42 | 92·48 | 95·70 |
| $SiO_2$ . . . . | 5·96 | 5·74 | 3·75 | 1·00 |
| $Al_2O_3$. . . . | 0·50 | 0·30 | 1·00 | 7·00 |
| $P_2O_5$ . . . . | 0·04 | 0·067 | 0·10 | 0·024 |
| S . . . . . | 0 027 | 0·025 | ... | 0·014 |
| Mn . . . . | 0·264 | ... | ... | ... |
| CaO . . . | ... | 0·560 | ... | 0·54 |
| Metallic iron . . | 64·50 | 64·00 | 64·63 | 67·00 |

| | Novotro-ensky Ore. | Nicolaeff-sky Ore. | Stileffsky Ore. | | | Karakoubsky Ore. | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | No. 2. | No.116. | No. 4. | No. 5. | No. 51. | No. 7. | No. 8. |
| $Fe_2O_3$ . . | 76·14 | 71·43 | 71·43 | 70·00 | 64·24 | 73·00 | 73·00 | 76·14 | 73·00 |
| $SiO_2$ . . | 8·70 | 17·50 | 12·00 | 20·00 | 16·00 | 13·30 | 14·40 | 7·50 | 8·00 |
| $Al_2O_3$ . . | 5·00 | 4·00 | 5·98 | 5·00 | 8·00 | ... | ... | 3·50 | 3·10 |
| S . . | ... | ... | ... | ... | ... | ... | ... | ... | ... |
| $P_2O_5$ . . | 1·00 | 0·438 | 0·13 | 0·25 | 0·09 | 0·10 | 0·115 | 0·167 | 0·77 |
| Mn . . | ... | ... | 4·00 | ... | 8·00 | ... | ... | ... | ... |
| CaO . . | 2·35 | 0·335 | ... | ... | ... | ... | ... | 3·00 | 7·90 |
| Metallic iron | 53 | 50 | 50 | 49 | 45 | 51 | 51 | 53 | 51 |

*Coals from the Smolianinoffsky Seam.*—An assay of coal after being three days in a room at 17° C. gave the following percentages :—Ash, 2·56; sulphur, 0·35; coke, 79·07; non-volatile organic matter, 75·93; volatile matter, 20·75; moisture, 1·0. Dried over sulphuric acid during four days the coal yielded :—Ash, 2·59; sulphur, 0·36; disposable hydrogen, 3·14; nitrogen and oxygen, 10·60; hydrogen, 4·46; carbon, 81·99. Specific gravity, 1·298; calorific power calculated from analysis 7690 calories; evaporating power, 14·32; 100 parts of the organic

matter of the coal yielded: volatile matter, 21·60; coke, 78·40; carbon, 84·48; hydrogen, 4·57; oxygen and nitrogen, 10·95.

*Coal from the Livensky Seam.*—From 100 parts of coal, after being three days in a room at 17° C., there was obtained:—Ash, 3·59; sulphur, 0·72; coke, 72·25; non-volatile organic matter, 68·50; volatile organic matter, 26·86; moisture, 0·89. In 100 parts of coal, dried over sulphuric acid during four days:—Ash, 3·63; sulphur, 0·73; disposable hydrogen, 3·30; nitrogen and oxygen, 12·45; hydrogen, 4·86; carbon, 78·33. Specific gravity, 1·300; calorific power, 7451 calories; evaporating power, 13·87.

*Coal from the Semeonoffsky Seam.*—100 parts, after being three days in a room at 17° C., yielded:—Ash, 3·75; sulphur, 0·66; coke, 63·70; non-volatile organic matter, 59·62; volatile organic matter, 35·01; moisture, 0·96. In 100 parts, dried over sulphuric acid during four days:—Ash, 3·79; sulphur, 0·67; disposable hydrogen, 3·33; nitrogen and oxygen, 12·32; hydrogen, 4·87; carbon, 78·35. Specific gravity, 1·292; calorific power, 7463 calories; evaporating power, 13·89.

*Coke from the Smolianinoffsky Coal.*—100 parts, after being three days in a room at 17° C., yielded:—Ash, 8·08; sulphur, 0·68; coke, 99·79; non-volatile organic matter, 91·03; volatile organic matter, 0; moisture, 0·21. In 100 parts dried over sulphuric acid during four days:—Ash, 8·10; sulphur, 0·69; disposable hydrogen, 0·19; nitrogen, oxygen, 1·06; hydrogen, 0·32; carbon, 89·83. Specific gravity, 1·945; calorific power, 7525 calories; evaporating power, 14·01. This coke is considered the best made in the Don basin.

*Iron.*—Cast iron for sale:—Carbon (graphitic), 3·595; carbon (combined), 0·511; silicon, 2·111; sulphur, 0·024; phosphorus, 0·593; manganese, 1·685. Pig iron for steelmaking:—Carbon (graphitic), 3·109; carbon (combined), 0·620; silicon, 1·810; sulphur, 0·031; phosphorus, 0·070; manganese, 0·216.

*Manganese Pig.*—Manganese, 45·5; carbon, 4; silicon, 1; phosphorus, 0·25; iron, 49·25.

*Open-hearth Steel (Rails).*—Carbon per cent., 0·400; silicon, 0·030; sulphur, 0·034; phosphorus, 0·072; manganese, 0·700.

The Alexandroffsky, or Briansk Works, as they are often called, are situated on the right bank of the River Dnieper about a mile from the town of Ekaterinoslav.

The plant of the Ekaterinoslav works is calculated for the production of 50,000 tons of steel rails and 25,000 tons of iron of various sorts. For the manufacture of the above quantity of rails and iron,

more than 250,000 tons of raw material, ore, coke, flux, and coal are necessary.

The Ekaterinoslav blast furnaces are Scotch furnaces with iron casings. The shaft of each furnace is supported by six iron columns of rectangular section, similar to those at the Kamensky, and giving the whole structure greater stability and durability than can be obtained with columns of circular section. The furnaces are furnished with conical funnel gas collectors. The waste gases are led to the Cowper stoves, three to each furnace. A pneumatic lift serves to raise the raw material to the furnace top. There is a special pneumatic pump situated behind the furnaces in a separate house. The cage of the lift (tare with two loaded waggons, 2 tons) is connected with the pneumatic cylinders by two flat steel ropes. The furnace is charged by means of a variety of cup and cone charger. The unprotected character of these furnaces is not quite suitable to the climate, as in winter the water-pipes often freeze. Both furnaces are of similar construction and dimensions. There are five tuyeres 3·54 inches in diameter. The total height of the furnace is 65½ feet, and the internal height is 59½ feet. The useful capacity of the hearth is 70 cubic feet, so that it is possible to collect 14·7 tons of iron in the hearth between each tapping. The usual quantity tapped at a time is 9·67 to 11·3 tons. The furnace is tapped five or six times per day. No. 1 furnace during August 1887 yielded 57·4 tons per day. The maximum yield was 72 tons on the 12th July 1888. The pig iron was Nos. 1 and 2 grey. The second furnace, No. 2, has been in blast since June 1888, and has a daily yield of 40·32 tons. No. 1 furnace was put in blast on August 30, 1887, and since then its monthly yield has been :—1887 : September, 920 tons; October, 1048; November, 1162; December, 1300. 1888: January, 1530; February, 1490; March, 1550; April, 1550; May, 1580; June, 1560; up to July 15, 820—total for ten and a half months, 14,510 tons.

The manufacture of 1 ton of pig iron requires the consumption of 1·12 ton coke, 1·5 ton ore (67 per cent. rich, and 33 per cent. poor Krivorogesky ore), and 0·381 ton flux. The pressure of the blast is 7·5 inches of mercury, and its temperature 600° to 780°. During the four months ending November 1, 1888, 13,000 tons of pig iron was tapped.

There are three direct-acting blowing-engines of the Cleveland type, having the steam cylinder placed over the air cylinder. They have all three exactly similar dimensions. Diameter of air cylinder, 8 feet;

diameter of steam cylinder, 4 feet; stroke of piston, 5 feet. The normal number of revolutions per minute is 18 to 22. The average velocity of the piston is 3¼ feet. The pressure of air 3½ to 4 lbs. or 6½ to 7½ inches of mercury. The quantity of air at the atmospheric pressure and normal temperature served per minute by each engine is 7910 cubic feet per minute, so that the ratio of the volume of air to the capacity of the furnace is 1 : 1·07.

Six sorts of pig iron are made at the works—namely, grey, Nos. 1, 2, 3; forge, No. 4; mottled, No. 5; white, No. 6. The cost of smelting with ore from the Krivy Rog at 24s. per ton is as follows:—No. 1, 81s. 10d. per ton; No. 2, 71s. 11d.; No. 3, 70s. 8d.; No. 4, 69s. 5d.; No. 5, 68s. 2d.; No. 6, 66s. 11d. Pig iron on the spot sells at 93s. to 100s. per ton.

The small and medium rolling mills and eight puddling furnaces have been recently opened. Eight more puddling furnaces are ready for work, and the remaining sixteen puddling furnaces and the large rolling mills are expected shortly to be ready. Each puddling furnace has a capacity of 440 to 560 lbs. The small and medium rolling mills can turn out 25 to 32 tons of manufactured iron per day. The open-hearth furnaces are nearly ready, but not working for want of fuel. The building of the Bessemer converter department and of the large rolling mills is stopped until the spring, when it is also proposed to begin building two more large blast furnaces each of 13,243 cubic feet capacity. The two blast furnaces now in work, with all their accessories, cost £80,000.

The works of the South Russian Dnieper Company, otherwise known as the Kamensky Ironworks, which are of Belgian design, consist of an entirely new blast furnace plant, while the rolling mills and other machinery have mostly been transferred from the abandoned Warsaw Works. The works are situated on the right bank of the River Dnieper, and are connected with the main line of the Ekaterininsky Railway by a branch line from Zaporoshie.

The blast furnace section of the Kamensky Works contains two Scotch blast furnaces, eight Whitwell hot-blast stoves, three blowing-engines, and all the necessary accessory tram lines and stores. It is proposed to afterwards erect coking ovens. Both blast furnaces are of exactly similar construction and dimensions. The shaft, which is built quite separately from the hearth, is supported on eight cast iron columns. The foundations lie at a depth of 10 feet below the soil, and are so disposed that the pressure of the furnace when fully charged does not exceed

45·75 lbs. per square inch. The furnaces are not entirely iron cased, but braced by twenty-eight iron hoops. The waste gases are collected by a Hoff's gas collector. The dimensions of the furnace are as follows:—Height, 72 feet; diameter at boshes, 19½ feet; diameter at throat, 16½ feet; diameter at the lower part of hearth, 6½ feet; total capacity, 14,126½ cubic feet. The daily yield will be 120 tons of grey pig iron, or 1 ton per 116·5 cubic feet. The annual yield of the two furnaces is calculated at 64,000 to 70,000 tons. The cost of erection of each furnace was £14,825. Between the furnaces are erected two endless wire rope lifts. Each lift has two cages, and is worked by a 10 horse-power compound reversing engine. The ropes are 1¼ inch in diameter, with strands 0·45 inch in diameter. The winding drums are 10 feet in diameter. Each lift, with all accessories, cost £3470. There are four Whitwell hot-blast stoves to each furnace. They are 57 feet high and 21·64 feet in diameter. The heating surface of each stove is 26,900 square feet. The cost of each stove was £4450. They have a common chimney, 164 feet high and 9½ feet in diameter. Its erection cost £770, and it is built of 12,200 red and 3200 fire bricks. In working the stoves, one is alternately heated by the waste gases, while three are employed in heating the blast.

The casting-house is entirely made of iron, and contains a row of three cupola furnaces, which are used to remelt the pig iron cast on holidays or when the Bessemer converter is not at work. The molten pig iron is either run from the cupola furnaces or else direct from the blast furnaces into an iron truck, and taken by a locomotive to the Bessemer department. There is also a casting-yard before each blast furnace. The cupola furnaces are 22½ feet high and 5 feet in diameter, the diameter of the hearth being 4¼ feet. With one series of tuyeres their yield is 4 to 5 tons per hour each, and with two series of tuyeres their yield increases to 12 to 15 tons. The blast is supplied by a Root's blower. The erection of the casting-house cost £8500.

In the blowing-engine house there are three large vertical blowing-engines, made at Seraing, in Belgium. These engines (Woolf's system) are similar to those in use at Messrs. Cockerill's works; they are condensing engines with two steam cylinders placed below the air cylinder. The diameter of the high-pressure cylinder is 47·25 inches, and the diameter of the low-pressure cylinder 33·5 inches. The diameter of the air cylinder is 10 feet, and the stroke of the piston 8 feet. The normal number of revolutions per minute is twelve, and the normal velocity of the piston 3·28 feet per second. The quantity of blast (at

the atmospheric pressure) served per minute is 15,183 cubic feet, or 1·125 cubic foot per cubic foot of the capacity of the blast furnace, or 108·75 cubic feet per ton of pig iron daily. The pressure of the blast will be 9·6 inches of mercury. Only two of the engines will be worked at a time, one being kept as a reserve engine. The whole cost of the engine-house with two engines and the foundation for the third was £22,000.

The blast furnace department is furnished with eight double cylindrical boilers. Each boiler consists of two water tubes, 39 feet long and 4·25 feet in diameter, and two heating flues, 33 feet long and 3 feet in diameter. The heating surface of each boiler is 1388 square feet. It is proposed to heat the boilers by the blast furnace waste gases. The chimney for this group of boilers is 164 feet high and 10 feet in diameter; its upper sectional area is 38 square feet per blast furnace, or 1-147th of the total heating surface of the boilers. The erection of these boilers and all their accessories cost £14,000.

With a view to obtaining the necessary ore, the company has leased three properties on the Krivy Rog. The ore deposits on these properties extend over four miles, and mostly lie parallel to each other. The ore occurs in a quartzose schist that is so rich in ore that it can be profitably mixed with the ore in making up the blast furnace charge. The ore, a kind of red hæmatite, is very rich, containing, as it does, from 65 to 71·5 per cent. of metallic iron. In some places the ore is found at the surface, and at others at a depth of 10 fathoms. The thickness of the deposits has not yet been determined. It is proposed to smelt this ore alone. The following is an analysis of the ore:—Silica, per cent., 3·06; ferric oxide, 95·59; alumina, 0·94; phosphorus, 0·02; manganese, none; lime, magnesia, sulphur, traces; moisture, 0·98; metallic iron, 66·91. In June 1888 as much as 32,000 tons of ore had already been raised from the preliminary workings, and the mines are laid out for a yearly yield of 97,000 tons of ore.

**The Mayville Blast Furnace.**—The blast furnace erected at Mayville, 50 miles to the north of Milwaukee, is 67 feet high, by 13 feet 9 inches in diameter at the boshes. It was remodelled by Mr. J. Birkinbine in 1887–88, and a peculiar device is used for cooling the walls, water being conveyed by a series of coils and water-boxes high up the stack, far above the boshes. The lowest tier of coils consists of pipes arranged vertically and placed very close together. The

water-boxes, further up, consist of iron boxes set deep in the stack, each containing a coil of pipe through which the cold water passes. The highest pipes are arranged horizontally, and this arrangement has been found to work well in preserving the lining. A Weimer vertical blowing-engine is used, having an air cylinder 6 feet in diameter with a 72-inch stroke, and a steam cylinder 32 inches in diameter with a 48-inch stroke. The Weimer charger is also employed. A mixture of Lake Superior and local flaxseed ore is used. At the present time the percentage of local ore is from 30 to 40, but the furnace will be worked up to 50 or more very shortly, as it gets into proper shape. About 50 tons of pig iron are now made daily, but the output will be considerably larger when the furnace is working up to its full capacity. An inclined-plane double-track hoist is used.*

**An American Blast Furnace.**—A blast furnace erected at Bellefontaine,† Pennsylvania, is 70 feet in height, 15 feet in diameter at the boshes, and 8 feet at the crucible. The total capacity of the furnace is 72,000 cubic feet. In its first year's run it made 27,127 tons of pig iron, an average of 81 tons a day. The ore used was hæmatite from the Buffalo Run and Barrens mines. The average percentage composition of this ore is as follows:—

| Iron. | Silica. | Phosphorus. | Sulphur. |
|---|---|---|---|
| 49–52 | 15–28 | 0·08–0·16 | 0·0–0·04 |

Connellsville coke was used, and the necessary limestone was quarried in the immediate neighbourhood of the furnace.

**The Hinkle Charcoal Furnace, Wisconsin.**—On February 19, 1889, the output of this charcoal blast furnace,‡ which is situate at Ashland, Wisconsin, reached 111 tons. This is the highest recorded day's output of any charcoal blast furnace. The furnace stack is 60 feet in height, and 12 feet in maximum inside diameter. The ore used is that found in the neighbourhood, in the Gogebic Range. The works are situated on Chequamegon Bay, Lake Superior, and extensive forests of hardwood timber occur in the immediate vicinity. The arrangement of the furnace plant is also described.

**American Blowing-Engines.**—The blowing-engine erected at the works of the Ashland Iron and Steel Company, Wisconsin, is of

* *Iron Age*, vol. xliv. p. 486. † *Ibid.*, vol. xliii. p. 357.
‡ *Ibid.*, p. 465.

the vertical direct-acting type, having the steam cylinder below, and the air cylinder above. The steam-cylinder is 34 inches in diameter, and has a 4-foot stroke; it is fitted with a Reynolds-Corliss valve gear. The air cylinder is 78 inches in diameter, with a 4-foot stroke, and has the Reynolds patent positive-motion air valve. The two fly-wheels weigh 31 tons, and the total weight of the engine is 92 tons. The speed is controlled by a fly-ball governor attached to the cut-off cams of the steam-valve, and can be varied from 12 to 50 revolutions by simply turning a hand-wheel, the engine remaining absolutely under control of the governor. At 50 revolutions the capacity is 13,000 cubic feet of air per minute.

The special feature of the machine is the valve gear of the air cylinder, which was designed by Mr. E. Reynolds. In each cylinder head are two rolling valves, each 16 inches in diameter, one being the inlet, and the other the discharge. The inlet valves are opened and closed positively by means of a direct connection with a wrist-plate. The discharge valves are closed at the proper time by the same wrist-plate that drives the inlet valves, but are opened automatically when the air in the cylinder reaches the same pressure as the air in the blast-pipe leading to the furnace. The wrist-plate is driven by an eccentric on the main shaft of the machine through suitable connection. The connection between the wrist-plate and the delivery valve is by means of a rod slotted to receive a pin on the actuating arm of the valve, and is positive in its motion only at such time as the rod is moving towards the cylinder head and acting upon the valve to close it. When the motion of the wrist-plate is reversed, the slotted end of the rod permits the reverse motion of the wrist-plate and rod to take place, while the delivery valve remains closed, being held in that position by a hook or catch until it is automatically released and allowed to open. Attached to the stem of the valve is an arm, provided at its outer end with a pin and block, on which is also attached by pin and rod a weight working in a dash-pot. To a fixed pin is pivoted a hook provided with a tailpiece engaging with the block. The piston-rod of the piston of a small cylinder is so arranged as to disengage the hook at the proper time to allow the weight to open the delivery valve. When this valve is closed the piston-rod is free of the hook, and yet so near that a short movement will cause it to bear against and release the hook. The small cylinder is connected by a pipe in its top with the receiver or blast-pipe leading to the furnace, whilst a second pipe connects the other end with the end of the main

cylinder, so that on one side of the piston there is always the pressure of the air in the receiver, whilst on the other side there is whatever pressure there may be in the main air cylinder.*

The new blowing-engine of the Shenandoah Furnace Company, Virginia,† is of the ordinary vertical type, having a steam cylinder 38 inches in diameter, an 84-inch blowing cylinder, and a stroke of 48 inches. A piston valve is employed on the steam cylinder. The inlet air valves are round steel plates, faced with leather, placed in the cylinder heads, opening vertically into the cylinder, and closed by light springs. The outlet valves are similar in construction and size to the inlet valves, but are made of bronze with leather faces. The description is accompanied by 8 illustrations.

**Improved Cowper Stoves.**—F. W. Lürmann ‡ describes three modifications of the ordinary form of Cowper stove arranged so as to increase the distribution of the combustion products, and to equalise the temperature to a greater extent than is usual. There is a tendency for the gases to pass through the central portion of the stove rather than elsewhere, and this naturally reduces its heating capacity. To avoid this, M. Boecker enlarges the relative size of the openings at the sides of the stove. This the author considers to be of little use. The Champigneulles and Neuves Maisons Works, France, have adopted a simpler and more logical method. At these works the central openings are partially closed up by brickwork at the base, this temporary brickwork being removed when the stove is cleaned. By this means the number of openings so closed can be regulated at will to suit the conditions of the working, without diminishing the heating surface, as is the case in the other arrangement described above. A third method was adopted by the author. This consists in replacing the usual iron grate by brickwork arranged in such a manner that without alteration in the size of the opening the hot combustion products are compelled to pass in equal volumes through the various openings of the stove.

**Firebrick Hot-Blast Stoves.**—In a paper read before the United States Association of Charcoal Iron Workers at the Milwaukee meeting, Mr. V. O. Strobel discussed the relative value of the several kinds of firebrick stoves now in use. Referring to the thickness of the firebricks

* *Iron Age*, vol. xliii. p. 691, 3 illustrations.
† *Ibid.*, vol. xliv. pp. 117–119.
‡ *Stahl und Eisen*, vol. ix. p. 774.

employed in the construction of the flues, in the author's opinion $4\frac{1}{2}$ inches is a sufficient thickness, and is as efficacious in practice as a thickness of 9 inches. In the type of stove preferred by Messrs. Gordon, Strobel & Laureau of Philadelphia, $\frac{3}{16}$-inch casing plates are used for the 16 by 18-foot stoves, and $\frac{5}{16}$-inch plates for the 20-foot stoves. The stoves attached to anthracite furnaces, employing as they do very high pressures, require a very strong casing, for which purpose steel plates are employed. Between the casing and the outer wall of firebrick a 1-inch space is left to admit of the expansion of the brick-work. A set of three 18 by 65-foot stoves erected at the Hanging Rock Region would cost about £6000. It is not possible to prevent the glazing of the bricks in the stove, desirable as this would be.

In order to increase the efficiency of hot-blast stoves, Mr. J. T. Wainwright * suggests a modification in their construction whereby air and gas are heated before combustion. The stove is divided by four vertical partitions which terminate before they reach the top of the stove. Blast furnace gas and air for combustion are admitted through two of the divisions and combine in the combustion chamber at the top. The products of combustion pass down and heat the other two divisions. By frequent reversals the top of the stove is most highly heated, and the bottom chequer-work, which sustains the weight, is kept cool. The air and gas are both heated before combustion, and do not make one side much cooler than the other if the reversals are frequent enough. The air for the blast is admitted at the bottom and led from the top of the stove after passing simultaneously through all divisions.

**Pipe Hot-Blast Stove.**—H. Schulze-Berge † describes a new hot-blast stove in which, instead of the flame passing round the pipes and the blast through them, the flame is led through the pipes and the blast circulates round them. The stove consists of a wrought iron box lined with fireclay, with horizontal plates in which the pipes are fixed, and a middle vertical division-plate. The blast passes up one side of this division and down the other, and the flame is led up through one half of the pipes, passes under the cover, down the other half, and escapes at the bottom of the stove.

**Charging Barrows.**—In a new charging barrow of American construction, the box is of the old form, and is supported on

* *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 680-683.
† *Dingler's polytechnisches Journal*, vol. cclxxii. p. 9.

gudgeons in bearings attached to a framework. To this frame the wheel-axles are attached independently of the box; they are large, and made of wood, so as to run easily. The gudgeons are fixed on the box near its centre of gravity, so that it returns to position when empty, but tilts over on release of a bolt by a thumb trigger when loaded. The whole barrow is designed so that but little weight comes on the labourer's hands, and the lift required to load it is small, as the box lies in the frame between the wheels.*

**The Roberts Tuyere Stock.**—Mr. F. C. Roberts † has designed a tuyere stock which is intended to overcome the difficulty that is experienced in using tuyere stocks in which one section is movable, owing to the great weight of the movable part. In the Roberts tuyere stock the movable part is of short length and easy adjustment.

**Tuyere Slagging Valve.**—Mr. E. S. Cook ‡ describes a tuyere slagging valve for relieving the tuyeres of slag which is likely to fill them when the crucible cools or the stock falls. In 1887, while working on anthracite alone, the Warwick furnaces, Pennsylvania, gave great trouble from the slag running into the tuyeres, and all ordinary expedients were useless. To clear out the tuyeres the dangerous process was adopted of removing the keys and holding the caps in position with props, which were knocked away at a given signal while the engine was running. As the slag had to be removed and the caps closed with considerable delay, the working of the furnace was very much interfered with.

As an expedient to overcome this, it is proposed to place in the cap or bottom of the tuyere, a valve which could easily be opened to flush out the pipes. The valve is carried by an arm with a toothed-sector gearing with a rack. The rack is connected to a piston working in a cylinder which is supplied with air from the main by means of a three-way cock. The area of the piston is larger than that of the valve, so that the valve is held closed till the three-way cock is turned to exhaust the air from the cylinder. A second three-way cock may be introduced to admit air to the other side of the piston in order to hold the valve open while slag is flowing from it. The cocks are placed so that the workmen can open the valves with perfect safety while the slag flows out or is blown out.

* *American Manufacturer*, vol. xlv. No. 12.
† *Iron Age*, vol. xliii. p. 694, 1 illustration.
‡ *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 389–397.

It is found that 3-inch valves are most convenient in size. One 6-inch valve has been made; in this case the cap itself is the valve, and carries eye-hole and pricker-hole. On one occasion the engine suddenly stopped and the pipes filled with slag. The 6-inch valve opened automatically by the pressure of the slag, the others were easily opened with a small bar. The shell of slag was cleared and everything restarted in half an hour's time. These valves are found to give perfect satisfaction, and are even opened once or twice a day to clean out the tuyeres.

**Flue Dust.**—A small percentage of zinc in the ores of Low Moor, Virginia, according to Mr. E. C. Means,* sometimes gives rise to trouble in working the furnaces. In one case a mass of nearly 6 tons of zinc oxide was attached to the lining below the tunnel head. A dust catcher with a small bell is used to reduce the amount in the flues. The bell is lowered at least twice, and the daily yield is 600 to 1000 lbs. An analysis gave 87·66 per cent. of zinc oxide, or 70·36 per cent. of metallic zinc. It also contained iron, manganese, lime, alumina, silica, phosphoric, and sulphuric anhydrides. An analysis of the dust taken 150 feet from the furnace showed 30 per cent. of metallic zinc.

## II.—*CHEMICAL COMPOSITION OF PIG IRON.*

**American Pig Iron.**—According to Lagerwall,† the following are the six most notable types of pig iron made in the United States:— 1. The Poughkeepsie iron, made in New York with anthracite, from two-thirds of magnetite and one-third brown hæmatite. It is especially adapted for castings, and contains approximately 4·24 per cent. of carbon, 3·00 silicon, 0·15 phosphorus, 0·05 sulphur, and 1·46 manganese. 2. The Bushong pig iron of Pennsylvania, made from similar material, and containing 3·34 carbon, 1·93 silicon, 1·09 phosphorus, 0·013 sulphur, and 0·14 manganese. 3. Pig iron made from red hæmatite at the Franklin and Alice furnaces in Alabama, with a high temperature and rapid blast, contains 4·85 silicon and only 2·96 carbon. The Rising iron of Georgia, containing 1·74 silicon and 4·23 carbon, is of good quality. In the Southern States the proportion of manganese is usually very low. 4. The Dayton pig iron is made in

* *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 129-131.
† *Jernkontorets Annaler*, vol. xliii. pp. 361-373.

Tennessee; it contains somewhat more phosphorus. 5. The pig iron from the carbonate ores of Ohio contains more than 6 per cent. of silicon; its consumption increases, as it can advantageously be used to increase the percentage of silicon in foundry mixtures. Grey foundry iron contains 2·58 carbon, 6·67 silicon, and 0·50 phosphorus. 6. Detroit charcoal pig iron, made from Lake Superior ores, contains 1·57 silicon, 0·24 phosphorus, and 0·04 silicon; it is quite pure, and is useful for cast railway wheels.

The titaniferous iron ores of Lake Superior have not yet been successfully treated, as the percentage of titanium is very variable. The proportion of sulphur and phosphorus is, however, very low, and qualifies these ores for the charcoal blast furnace. The ores consist approximately of 11·93 per cent. of silica, 7·90 to 12·00 titanic anhydride, 65·47 to 85·00 magnetite, 5·63 alumina, 2·93 lime, 5·08 magnesia, and traces of sulphur and phosphorus.

**Spanish Pig Iron.**—The following are analyses of the pig iron produced at the Viscaya Works, Spain: *—

| | I. Very Grey. | II. Grey. | III. Grey. | IV. Grey. | V. Light Grey. | VI. Mottled. | VII. White. |
|---|---|---|---|---|---|---|---|
| Silicon . . . | 3·000 | 2·400 | 1·800 | 1·400 | 1·000 | 0·800 | 0·600 |
| Manganese . . | 1·000 | 1·000 | 0·900 | 0·750 | 0·600 | 0·500 | 0·400 |
| Sulphur . . | 0·015 | 0·020 | 0·030 | 0·050 | 0·060 | 0·100 | 0·150 |
| Phosphorus . . | 0·040 | 0·040 | 0·040 | 0·040 | 0·040 | 0·040 | 0·040 |

**Ferro-chrome.**—R. Busek † points out that the manufacture of chromium iron alloys rich in chromium is an industry of modern date. The ferro-chrome now produced contains usually from 20 to upwards of 75 per cent. of chromium. Thus the Terre-Noire Company produces an alloy of the following percentage composition:—

| Fe. | Cr. | Mn. | C. | Total. |
|---|---|---|---|---|
| 57·43 | 25·30 | 13·20 | 4·75 | 100·68 |

At Unieux rich and pure chrome ores from Greece and the Ura have been smelted in crucible-steel crucibles, yielding a ferro-chrome containing from 50 to 60 per cent. of chromium. The average composition of the ore treated was as follows:—

| FeO. | $Cr_2O_3$. | $Al_2O_3$. | MgO. | $SiO_2$. |
|---|---|---|---|---|
| 18·0 | 39·1 | 27·6 | 11·6 | 3·0 |

* *Stahl und Eisen*, vol. ix. p. 859.

† *Ibid.*, vol. ix. pp. 727–729.

In order to produce an alloy very rich in chromium use was made at Unieux of potassium dichromate. The main difficulty connected with the economic manufacture of these alloys consists in the difficulty with which the chromium is reduced. From this cause the output of a blast furnace sank to 11 or 12 tons a day, 3 tons of coke being used for each ton of the chrome iron produced. The production of chrome-iron-manganese is, however, now very easy. H. Echardt's process,* which consists in smelting the chrome ore with cinder from the acid Bessemer converter, and with manganese ore, yields good results, the metal and slag separating with great readiness, the manganese in the alloy adding greatly to the fluidity of the metal.

When molten ferro-chrome is exposed to the action of the atmosphere it becomes covered with a green film of chromium oxide; the chromium slags, on the other hand, become covered with a brown film on cooling, due, it is thought, to the formation of a chromate.

With regard to the influence of chromium on iron, the addition of chromium to unhardened steel greatly increases the limit of elasticity and the ultimate tensile strength, without, however, affecting the degree of elongation which would be due to the percentage of carbon also present. A chrome steel may possess the same power of resistance to stress as a hard carbon steel, but it will not be so brittle. An addition of chromium by itself will not impart to iron the property of becoming hardened on quenching in water, but a chrome steel containing carbon is easier to harden and becomes much harder than does a steel with the same percentage of carbon, but which contains no chromium. Unhardened chrome steel is difficult to fracture, and shows a very fibrous structure. By hardening at suitable temperatures the texture of the metal becomes the more finely granular the higher the percentage of chromium and of carbon. When the percentage of carbon reaches 4, the metal is so hard that ordinary tools will not touch it. If, however, such steel is hardened in water, it becomes fragile. One of the peculiarities of chrome steel is that the oxide scale on the surface of the metal does not separate from the metal when it is plunged into water from a red heat. Chrome steel deteriorates in quality if it is heated to too high a temperature, or for too lengthened a period. Such steel, too, solidifies at a much higher temperature than does ordinary carbon steel, and whilst of very fine grain and extremely hard, it is more affected by sudden shock than it is by a steady stress. For certain classes of tools it is better than the very best crucible

* *Journal of the Iron and Steel Institute*, 1889, vol. i. p. 311.

steel. Chrome steel may be readily bent in the cold; it may be welded with iron, and then rolled, and in this form finds considerable use. The following are analyses of chrome irons exhibited at the Paris Exhibition :—

| | Chromium. | Iron. | Manganese. | Carbon. |
|---|---|---|---|---|
| 1 | 62·70 | 25·00 | 0·43 | 11·25 |
| 2 | 64·80 | 21·80 | 0·43 | 12·00 |
| 3 | 60·35 | 28·10 | 0·45 | 9·55 |
| 4 | 44·80 | 45·00 | 0·80 | 8·50 |
| 5 | 57·96 | 30·95 | 0·50 | 9·38 |
| 6 | 64·50 | 24·00 | 0·40 | 10·50 |
| 7 | 23·00 | 66·10 | 2·50 | 3·80 |

Nos. 1 to 6 are from the Adour Works, France, and No. 7 from the Firminy Works. This latter also contained 4·5 silicon, 0·08 phosphorus, and 0·02 sulphur.

**Analyses of Iron.**—Mr. E. Waller * sums up the results of analyses made by various analysts of three kinds of Swedish iron. The iron was stated not to be up to the sample analysis, and this gave rise to a dispute and trial in 1887. In some cases borings, in others pigs, were supplied to the chemists. The methods used and the results obtained are fully given. They are shortly tabulated as follows :—

| | No. of Analysts. | Maximum Variations of Different Analysts on the Same Pigs. | | |
|---|---|---|---|---|
| Phosphorus . . | 15 | 0·0419–0·053 | 0·0336–0·044 | 0·0405 –0·050 |
| Sulphur . . | 11 | trace –0·039 | 0·0008–0·033 | 0·00067–0·023 |
| Silicon . . . | 11 | 0·813 –0·961 | 0·769 –0·838 | 1·177 –1·26 |

| | Maximum Variations in the Same Brand. | | |
|---|---|---|---|
| Phosphorus . . . . . | 0·02–0·0544 | 0·033–0·0424 | 0·0402–0·050 |
| Sulphur . . . . . | 0·0 –0·039 | 0·0 –0·033 | 0·0 –0·023 |
| Silicon . . . . . | 0·72–1·152 | 0·796–1·113 | 0·69 –1·26 |

As regards phosphorus the difference between analysts is about 0·01 per cent., and this also is the variation in the same brand. As regards

* *School of Mines Quarterly*, vol. x. No. 3.

sulphur when small in amount the variations are very great, and this may be due either to imperfect methods of analysis or to great variation in the distribution. Probably both aspects require consideration. As regards silicon the analysts vary about 0·1 per cent., while in the same brand the differences are 0·5 per cent. With regard to methods of analysis, many kinds were tried and gave uniform results with each individual, so that there appears to be no particular preference for one over another.

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## III.—*BLAST FURNACE SLAGS.*

**Mica in Slag.**—Professor J. H. L. Vogt,* of Christiania, has discovered mica in a melilite slag from the Königin Maria Ironworks at Zwickau in Saxony. The mineral, which was isolated by treatment with hydrochloric acid and potassium hydrate alternately, was found under the microscope to be optically negative and biaxial. Distinct pleochroïsm was observed. The author regards this variety of mica as belonging to the biotite series. He has also discovered mica in slag from Kafveltorp works in Örebro, Sweden, and from the Garpenberg works in Sweden.

**A Fayalite Slag.**—A. Firket † has analysed a slag from the Ougrée Ironworks with the following results:—

| Silica. | Ferrous oxide. | Ferric oxide. | Manganous oxide. | Sulphur. | Phosphorus. |
|---|---|---|---|---|---|
| 28·00 | 62·00 | 9·30 | 0·97 | 0·14 | 0·50 |

The sulphur being subtracted as manganese iron sulphide, and the phosphorus as iron phosphide, there remains 82·69 $Fe_2SiO_4$, 1·17 $Mn_2SiO_4$, 12·21 $Fe_2SiO_5$, and only 0·42 $Fe_2O_3$ in excess. The hardness of the slag was found to be 6, and its specific gravity 4·212.

**Blast Furnace Slags.**—P. Gredt ‡ has made a series of experiments to ascertain the influence exerted by the presence of varying quantities of alumina on the melting-points of blast furnace slags. The influence which is exerted on the successful working of a blast furnace by the relative fusibility or infusibility of the slag becomes

* *Forhandlinger i Videnskapsselskabet i Christiania*, No. 6, pp. 1–42.
† *Zeitschrift für Krystallographie*, vol. xv. pp. 652–653.
‡ *Stahl und Eisen*, vol. ix. pp. 756–759.

evident when it is remembered that, whilst every kilogramme of pig iron requires for its fusion and necessary superheating about 285 calories, the same quantity of slag will require on the average 500 calories. A slag may be considered as a mixture of various compounds, soluble in one another at high temperatures, the constituents varying amongst themselves in their relative solubility.

In view of the high temperatures at which the experiments were to be made, no pyrometer appeared likely to give satisfactory results, and the author was therefore led to adopt the Seger test, in which 20 pellets of gradually increasing melting-points formed the scale, the supposed melting-points commencing at 1150° C. in the case of No. 1 pellet, and increasing to 1700° for No. 20, a difference of 29° between each pellet. Mixtures of alumina, lime, and magnesia were found to fuse at the temperatures shown in the following table:—

| No. | $SiO_2$. | $Al_2O_3$. | CaO. | MgO. | Temperature. |
|---|---|---|---|---|---|
| | | | | | ° C. |
| 1 | 1·8762 | 0 | 3·4965 | ... | 1570 |
| 2 | " | 0·1071 | 3·3217 | ... | 1526 |
| 3 | " | 0·2141 | 3·1469 | ... | 1492 |
| 4 | " | 0·3212 | 2·9720 | ... | 1468 |
| 5 | " | 0·4283 | 2·7972 | ... | 1451 |
| 6 | " | 0·5353 | 2·6224 | ... | 1439 |
| 7 | " | 0·6424 | 2·4476 | ... | 1430 |
| 8 | " | 0·7495 | 2·2727 | ... | 1422 |
| 9 | " | 0·8565 | 2·0979 | ... | 1417 |
| 10 | " | 0·9639 | 1·9231 | ... | 1412 |
| 11 | " | 1·0707 | 1·7483 | ... | 1410 |
| 12 | " | 1·1777 | 1·5734 | ... | 1430 |
| 13 | " | 1·2848 | 1·3986 | ... | 1468 |
| 14 | " | 1·3918 | 1·2238 | ... | 1526 |
| 15 | " | 1·4989 | 1·0490 | ... | 1613 |
| 16 | " | 1·6060 | 0·8741 | ... | above 1613 |
| 17 | " | 1·7130 | 0·6993 | ... | above 1613 |
| 18 | " | 1·8201 | 0·5245 | ... | above 1613 |
| 19 | " | 1·9272 | 0·3497 | ... | above 1613 |
| 20 | " | 2·0342 | 0·1748 | ... | above 1613 |
| 21 | " | 2·1413 | ... | ... | above 1613 |
| 22 | " | 1·0707 | 1·5734 | 0·1249 | 1378 |
| 23 | " | " | 1·3986 | 0·2497 | 1365 |
| 24 | " | " | 1·2238 | 0·3746 | 1357 |
| 25 | " | " | 1·0490 | 0·4994 | 1352 |
| 25a | " | " | 0·9907 | 0·5410 | 1351 |
| 25b | " | " | 0·9324 | 0·5826 | 1350 |
| 26 | " | " | 0·8741 | 0·6243 | 1352 |
| 27 | " | " | 0·6993 | 0·7491 | 1359 |
| 28 | " | " | 0·5245 | 0·8740 | 1368 |
| 29 | " | " | 0·3497 | 0·9988 | 1381 |
| 30 | " | " | 0·1748 | 1·1237 | 1410 |
| 31 | " | " | ... | 1·2485 | 1497 |

By means of these figures the author shows that the melting-points of any other mixture of silica, alumina, magnesia, and lime may be readily calculated.

Mr. A. D. Elbers * shows that the amount of sulphur in blast furnace slag is an indication of the contained silicates. Slag not containing sulphur is practically useless for manufacturing purposes, as the silica is high and the slag chills too quickly. Sulphurous slags, on the other hand, remain fluid for a longer time, but are likely to warp and to yield unsound castings which are "cold short." By the removal of the sulphur, these defects are also removed. The slag can be desulphurised by treating it in converters, while it is in the liquid state, with sodium nitrate. Other cheap fluxes may also be added to reduce the solidifying point. Each per cent. of sulphur will require about $1\frac{1}{2}$ per cent. of sodium nitrate for its combustion as expressed in the equation:—

$$10\,CaS + 12\,NaNO_3 = 10\,CaO + 6\,Na_2O + 10\,SO_2 + 12\,N.$$

Sodium chloride may also prove a suitable flux, especially when it is desired to get rid of iron by chlorination. These additions tend to make the slag more fluid if the bases are not increased beyond certain limits. In this way less sulphurous slags might be profitably treated. Desulphurised slag of favourable composition might remain plastic long enough for it to be balled up and compressed into suitable forms.

**Slag as Manure.**—Mr. W. R. Phillips † gives the composition of several forms of basic slag and other manures containing phosphorus. He shows that, commercially speaking, the value of the slag is often equal to, and sometimes even surpasses, that of other phosphatic manures. Most of the phosphorus in the charge goes into the pig iron, and then appears in the slag. The author has calculated the ratios, and finds that to produce a slag containing from 17 to 20 per cent. of phosphoric anhydride, the charge should contain from 0·65 to 0·76 per cent. of phosphorus. On an average one part of phosphoric anhydride from the pig iron yields 7·36 parts in the slag; some of the German works obtain as much as 9·3 parts.

**Slag-Grinding Mill.**—All the basic Bessemer slag made at the Rothe Erde Works, Germany, is cast into tank waggons, and is then taken to the grinding mill. The slag as it reaches the mill is still partly liquid, and this is poured on to iron plates to facilitate the breaking

* *The Engineering and Mining Journal*, vol. xlvii. pp. 522, 569.

† *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 84-94.

up. Thence it is charged into stone-breakers, whence it is taken in bucket elevators to the upper story of the mill. It is then passed through magnetic separators to remove any metallic iron that may be present. Two such machines are in use; they were constructed by Messrs. Kessler of Oberlahnstein. One, which is for the coarser material, consists of two drums, over which passes a leather belt studded with flat fingers of soft iron, about 1 inch broad, ¼ inch thick, and 2 inches in height. A core in the larger drum is rendered magnetic by the aid of a dynamo. While within its range, the iron studs on the belt are capable of holding the shots and pieces of metal which fall upon them with the broken slag. These pieces drop off the studs as the latter recede from the magnetic drum. The second machine is used for finer material. The principle of the construction is the same as in the case of the other machine, except that the studs are permanent magnets, from which the adhering metal is removed by the aid of brushes. Nearly all the intermingled metal is thus removed. The coarse slag is then ground fine on ordinary burr stones, the requirement being that 75 per cent. of the ground product must pass through a screen having 6000 meshes per square inch. The dust is exhausted by an elaborate series of fans, but the result is by no means perfect, and the wear and tear is excessive. The plant cost £3500, and its life is only about 2 years, the fine grit cutting the bearings, &c., very rapidly. The slag contains from 16 to 17 per cent. of phosphoric anhydride; the cost of grinding is from 14 to 15 shillings the ton, the selling price being from 20 to 25 shillings.*

## IV.—*FOUNDRY PRACTICE.*

**The Use of Softeners in Foundry Practice.**—Mr. W. Graham † describes the use that has been made of softeners in foundry practice by the Bellefonte Furnace Company, Pennsylvania. Owing to irregularity in the composition of the hæmatite ores, and of the limestone used, a small quantity of pig iron, containing from 3 to 6 per cent. of silicon, was made on first putting this furnace into blast, before the stock and burden were properly regulated. The composition of this iron was as follows:—

| Combined Carbon. | Graphite. | Silicon. | Phosphorus. | Sulphur. | Manganese. |
|---|---|---|---|---|---|
| 0·25 | 3 | 3–6 | 0·35 | 0·02 | 0·5 |

* *Iron Age*, vol. xliv. p. 121. † *Ibid.*, vol. xliii. pp. 915 952.

It was afterwards found that this grade of iron could be readily produced.

After an historical introduction, the author proceeds to discuss the use of the various elements present in silicon-iron, and gives the following analysis as representing the composition of No. 1 Bellefonte Foundry Iron :—

| Combined Carbon. | Graphite. | Silicon. | Phosphorus. | Sulphur. | Manganese. |
|---|---|---|---|---|---|
| 0·30 | 3·18 | 2·60 | 0·35 | 0·03 | 0·50 |

Combined carbon increases the hardness and brittleness of cast iron. Such metal shrinks more in cooling than does metal containing the carbon in the graphitic form. The presence of sulphur or manganese promotes the formation of combined carbon. Graphitic carbon, on the other hand, renders cast iron soft and tough. Silicon tends to cause the conversion of combined carbon into graphitic carbon, it increases the fluidity of cast iron, prevents shrinkage, and renders the metal difficult to chill. Sulphur hardens iron. It is powerful in its action, which is the inverse of that of silicon, 1 part of sulphur neutralising the effect of 5 or 10 parts of silicon. In soft foundry irons the percentage of sulphur should not exceed 0·13, for hard and mottled irons 0·20, nor for white irons 0·25. The presence of phosphorus induces hardness and brittleness; it increases the fluidity. Manganese renders the iron brittle. It causes the conversion of graphitic into combined carbon. It makes iron fluid, reduces shrinkage, and tends to produce clean castings.

**Tests of Foundry Mixtures.**—Messrs. Rodgers, Brown & Co., of Cincinnati, have published * the results of a series of tests of various foundry mixtures. The number of mixtures tested was 119, the test-pieces broken numbering about 300. These latter were 1 inch square and 24 inches in length between the supports. It was observed that nearly all the bars overran in size from $\frac{1}{32}$ to $\frac{1}{8}$ inch. The test-pieces were made chiefly at foundries in Ohio, Indiana, and Missouri, the mixtures being from coke and charcoal irons, the foundries using charcoal iron forming about 20 per cent. of the total number. The average strength of the test-pieces was 1120 lbs., 37 breaking below 1000 lbs., whilst 12 broke at above 1400 lbs., and 3 at more than 1500 lbs. One bar, in which wrought iron scrap and ferro-aluminium were mixed with pig iron, broke at 1958 lbs. This was the strongest bar examined, but it was difficult to drill or work. The next strongest bar was from a

* *Iron Age*, vol. xliii. p. 542.

mixture of coke irons, the weakest being from a mixture of No. 1 Lake Superior charcoal iron and old wheels. The experiments clearly showed that the best results were obtained rather by a suitable admixture of medium grade irons than by the use of the strongest and highest priced brands. The bending power of the bars tested was also observed, the maximum deflection being 0·53 inch, the minimum 0·25. In colour and grain, the general results were conflicting, the darkest fractures, and those of the cleanest, sharpest grains being sometimes among the weakest bars, although as a rule they were of good strength and soft. A mixture containing much silicon invariably proved weak and brittle, whilst similar results were observed if an insufficient quantity of silicon was present.

**The Grading of Pig Iron.**—At Birmingham, Alabama, according to Mr. K. Robertson,* there are eleven grades of pig iron. The grades are Nos. 1, 2, and 2½ foundry; Nos. 1 and 2 mill; Nos. 1 and 2 C.; Nos. 1 and 2 bright; Mottled, and lastly, White. A description of the various grades is given, and also the percentage of each produced. According to general classification, about 54·81 per cent. would be foundry iron.

**Iron for Castings.**—R. Åkerman † observes that it is customary to attribute a high percentage of graphite in pig iron to hot working in the blast furnace. It is less, however, directly to this cause that the separation of the graphite is due than to the high percentage of reduced silicon which a hot working produces. Sulphur, on the other hand, acts strongly in the opposite direction. The percentage of combined carbon is the greater the poorer the pig iron is in silicon, and the more rapidly the cooling of the molten metal was effected. Not only does the presence of much silicon reduce the percentage of combined carbon, but it also to some extent diminishes the percentage of total carbon which the iron will take up. Taken as a whole, coke pig iron as compared with charcoal iron is both richer in silicon and poorer in carbon, containing from 3 to 3·8 per cent. of this latter element, whilst charcoal iron contains from 3·8 to 4·5 per cent., and, on the whole, the percentage of silicon is in inverse ratio to that of carbon.

One of the main conditions on which the value of a casting is dependent is that, besides being free from blowholes, it should not be brittle,

* *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 94–96.
† *Jernkonterets Annaler*, vol. xliv. pp. 38–140.

and this again is dependent on the presence or absence of too much combined carbon. When but little phosphorus is present the percentage of combined carbon may reach 1·5, without rendering the casting brittle, but where much phosphorus is present, as is usually the case, the combined carbon should not exceed a few tenths per cent. On the other hand the percentage of combined carbon must not be too low and the phosphorus too high if castings of considerable strength are to be produced, for the strength, hardness, and specific gravity of the metal increase with the percentage of combined carbon. When the iron contains 0·25 per cent. of phosphorus, the greatest strength will be obtained with 0·8 to 1·4 per cent. of combined carbon, and it is absolutely certain that as the percentage of phosphorus increases, that of the combined carbon should become lower. It seems as though by a partial replacement of the combined carbon by silicon and phosphorus the strength of the metal is increased. Silicon, like combined carbon, though in a less degree, increases the strength of cast iron; but its action is less a direct one than by its influence on the state of the carbon. The direct action of silicon is indeed very different, as it not only does not diminish the brittleness of the iron but actually increases it, and increases the hardness. With regard to the influence of manganese, this element, like sulphur, but in a much less degree, causes the formation of combined carbon. Ordinary foundry iron may contain about half as much manganese as there is silicon present, without seriously affecting the action of the silicon, and it is even probable that a percentage of manganese such as this acts beneficially. For very strong iron a larger percentage of combined carbon is necessary than that present in ordinary foundry iron, and consequently the relative percentage of silicon must be diminished and that of manganese increased. The influence of phosphorus on the state of the carbon is also similar to that of sulphur, but its action is even less energetic than that of manganese. Like sulphur and manganese, it influences not only the condition of the carbon, but also diminishes the total percentage which the iron can take up. If a strong casting is required, the percentage of phosphorus may be as much as 1·5 without inducing brittleness, provided a sufficient quantity of silicon is present to keep the combined carbon down to a few tenths per cent. Phosphorus has the advantage of increasing the fluidity of the metal, and its presence even in considerable quantities may thus prove beneficial.

The author refers to the change in the character of pig iron produced by remelting, the loss of silicon this involves, and the change in state

of the carbon, and he refers to the experiments of Fairbairn and Jüngst on this question. The latter found the iron to undergo the following changes in composition :—

| Times Remelted. | Graphite. | Combined Carbon. | Silicon. | Phosphorus. | Sulphur. | Manganese. |
|---|---|---|---|---|---|---|
| 1 | 2·73 | 0·60 | 2·48 | 0·31 | 0·04 | 1·09 |
| 4 | 2·54 | 0·80 | 1·88 | 0·30 | 0·10 | 0·44 |
| 6 | 2·08 | 1·28 | 1·16 | 0·28 | 0·20 | 0·36 |

With regard to the fuel which is the most suitable for use in cupolas, experiments made at the School of Mines at Stockholm showed that more than five times as much carbonic oxide was produced when, under similar conditions, a current of carbonic oxide was passed through a red-hot porcelain tube filled with charcoal, as was obtained when the charcoal was replaced by coke; this ratio is found to increase with the temperature. These results show that charcoal is less suitable for cupola purposes than is coke, and for similar reasons the fuel should not be broken up too small. The author next proceeds to discuss the general internal shape of a cupola and the mode of working, the effort being by a suitable pressure of blast and a correct ratio between the size of the tuyeres and the diameter of the cupola, to produce a gas containing as little carbonic oxide as possible. The good results are referred to that have been obtained with the Greiner-and-Erpf cupola.

**Influence of Ferro-silicon on the Metal used in the Construction of Mining Engines.**—Sudden fractures of pumping engines are unfortunately not of infrequent occurrence. This is especially the case with the large valve-boxes of direct-acting pumps. Even the best grey cast iron has been found untrustworthy, whilst attempts to replace that material by cast steel have proved unsatisfactory on account of the porosity, hardness, and ductility of the latter. Jüngst * has consequently been impelled by Mr. F. Gautier's paper * to institute a series of experiments with ferro-silicon at the Royal Foundry at Gleiwitz. He melted numerous varieties of pig iron with ferro-silicon, and obtained a material whose limit of elasticity and breaking load approach closely those of wrought iron. By the addition of ferro-silicon, white cast iron melted in an Ibrügger cupola was rendered grey. The texture of this silicon cast iron exhibits a network of

* *Berg- und Hüttenmännische Zeitung*, vol. xlviii. p. 368.

steely iron with 5 per cent. of carbon with inclusions of graphitic seggregations. On analysis the iron yielded :—

| Si. | Combined C. | Graphite. | Mn. | P. | S. |
|---|---|---|---|---|---|
| 2·22 | 0·49 | 2·24 | 0·45 | 0·93 | 0·30 |

A cube of this iron, 1·18-inch side, broke after eleven blows, with an expenditure of 870 foot-lbs. of work.

A pump cylinder, 19·29 inches in diameter, 6·29 inches in thickness, and 2·1 tons in weight, was found to be thoroughly sound under a pressure of 280 atmospheres. The author is consequently of opinion that the manufacture of large machine parts by melting white pig iron with ferro-silicon is the only correct method.

The author further refers to the use of silicon in general for foundry purposes, and also to the possible extended use of aluminium for similar purposes.

**Cupolas.**—The success of the Herbertz cupola * has been so great that in three years in Germany alone 150 of these cupolas have been erected. During the three years the cupola has, according to Sahler,† passed through all phases of development. The chief advantage of this cupola consists in the production of a dense and soft cast iron, even from poor brands. This is due to the fact that through the uniform aperture for the admission of air passing around the body of the furnace, the exterior atmospheric air enters into the furnace at quite a low tension, effects the combustion of the coke, close above the aperture, with formation of carbonic anhydride, and thus melts the iron with as small as possible a withdrawal of carbon and silicon. The iron is not, as in other cupolas, rendered viscous in the upper portions of the furnace, but passes well-heated into the fusion zone. The consumption of coal in the production of the steam has been determined at the works of Sulzer Brothers. It is found to require 1·80 lb. for heating the boiler in order to melt 100 lbs. of iron. A cupola of this type at the Isselburg Works melts 4 to 5 tons of iron per hour. In trials recently made with heated air, the air was heated to 400° C. by means of the furnace itself, and it was found possible to melt steel and even wrought iron.

Baron von Manteuffel reports that, of the more recently invented cupolas, those of Herbertz and of Greiner and Erpf consume least material. At the Lauchhammer ironworks, a Herbertz cupola is in

* *Journal of the Iron and Steel Institute*, 1887, No. II. p. 296.
† *Dingler's polytechnisches Journal*, vol. cclxxiv. pp. 163–170.

operation, melting 3 to 4 tons per hour. It works very regularly, and the iron is melted within ten minutes of the application of the steam jet, and then drops without intermission into the hearth.

**Pig Iron for Wheels.**—Mr. A. W. Whitney * publishes the following analysis of the metal of which a remarkably strong wheel was composed. It was a 33-inch double-plate wheel, 569 lbs. in weight, the chill being good. It cracked slightly at the twentieth blow of a Pennsylvania railroad test drop, but had not broken after 425 such blows. It then broke at the third blow of a 600-lb. drop falling 12 feet. The chill was hard, ¼ inch deep at the root of the flange, and ½ inch deep in the tread. Analysis showed the following composition :—

| Combined Carbon. | Graphite. | Manganese. | Silicon. | Phosphorus. | Sulphur. | Copper. |
|---|---|---|---|---|---|---|
| 1·247 | 3·083 | 0·438 | 0·734 | 0·428 | 0·080 | 0·029 |

As a rule the author has found good chilling irons to contain from 0·56 to 0·95 per cent. of silicon. White irons often contain less than 0·15 per cent. Manganese may vary from 0·08 to 0·90 per cent.; phosphorus from 0·05 to 0·75; sulphur, 0·0 to 0·15 per cent.; and the total carbon always as high as the percentages of the above-mentioned constituents present will allow.

**Testing Cast Iron.**—A method of testing the strength of cast iron with a view to determining its resistance to shock is given by Prof. J. B. Johnson.† When cast iron is tested by an impact test, every blow permanently weakens the bar, so that when the specimen breaks the test only shows how much strength was left after the previous blows. The absolute resistance to shock may be determined by testing to rupture by a gradually increasing load, either in deflection or tension. From the data derived from either of these latter tests, the resilience of the metal, or the work performed in breaking it, may be determined by multiplying together half the breaking load by the deflection, and, further, this quantity is equivalent to the product of the weight and height of the tup in an impact test. If the resilience, as obtained above, be divided by the weight of the test bar, taking inches and pounds as units, the result will be the resilience of the iron in inch-pounds per pound of metal. This result is independent of the dimensions, but depends on the form, so that only bars of rectangular

* *Iron Age*, vol. xliii. p. 766.
† *The Age of Steel*, vol. lxvi., No. 11, 1 illustration.

section, uniform from end to end, should be used, and then the bar may be square or oblong in section indifferently.

By this method, therefore, after breaking any plain rectangular bar of uniform section, multiply half the breaking load in pounds by the deflection in inches, and divide the product by the weight of the bar in pounds. The result varies from 10 for the worst irons to 75 for the best. A result of 25 corresponds to the grade used for gas and water pipes, 40 to 50 to the better grades of machine castings, and stove irons give a result of 50 to 70.

The author has designed a simple apparatus which uses an ordinary platform scales for making the required tests. The bar is supported at its ends on knife-edges carried by tripods. One tripod is placed on the platform of a weighing machine registering up to 2000 lbs. The load is applied at the centre of the bar by a hand wheel and screw, which works in a standard on the trolley carrying the apparatus. Uprights spring from each tripod, and carry a horizontal reference bar with micrometer screw in the centre. The micrometer is adjusted to measure the distance through which the power screw moves downwards to the nearest thousandth of an inch, that is, to measure the deflection, and half the breaking strain is read directly from the lever of the weighing machine, provided the breaking strain is put on the centre of the bar.

## PRODUCTION OF MALLEABLE IRON.

**Manufacture of Wrought Iron Direct from the Ore.**—The Carbon Iron Company of Pittsburgh now use "retarded coke," according to Mr. A. E. Hunt,* in place of the graphite which he has previously described.† The coke is coated to retard its combustion by mixing 550 lbs. of coke-dust with seven bucketsful of a wash containing half a pound each of lime and fireclay per bucket. This amount of coke is well mixed with the furnace charge of 2240 lbs. of 65 per cent. ore, so as to give 25 to 30 per cent. carbonaceous matter to the charge. The average yield is 1550 lbs. of sponge, 1160 lbs. of squeezed blooms, or 1000 lbs. of muck bar. These latter give on analysis :—

| | Fe. | Si. | P. | S. | C. |
|---|---|---|---|---|---|
| Squeezed blooms . . | 98·47 | 0.940 | 0·020 | 0·021 | 0·150 |
| Muck bar . . . . | 99·020 | 0·560 | 0·015 | 0·010 | 0·100 |

In the open-hearth practice, 50 per cent. of sponge blooms, 40 per cent. of pig iron, and 10 per cent. of scrap are used. The waste from ore to ingots is less than 13 per cent.

The following are tests of plates rolled from ingots at these works :—

| Carbon. | Manganese. | Elastic Limit. | Ultimate Strength. | Elongation in 8 Inches. | Reduction of Area. |
|---|---|---|---|---|---|
| Per cent. | Per cent. | Lbs. per sq. in. | Lbs. per sq. in. | Per cent. | Per cent. |
| 0·12 | 0·35 | 34,000 | 50,000 | 30 | 65 |
| 0·14 | 0·35 | 36,000 | 55,000 | 28 | 62 |
| 0·18 | 0·35 | 40,000 | 60,000 | 26 | 56 |
| 0·22 | 0·35 | 44,000 | 65,000 | 25 | 50 |
| 0·25 | 0·35 | 48,000 | 70,000 | 23 | 46 |
| 0·30 | 0·35 | 50,000 | 75,000 | 22 | 42 |
| 0·35 | 0·35 | 53,000 | 80,000 | 20 | 40 |
| 0·40 | 0·35 | 56,000 | 85,000 | 18 | 38 |

* *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 668–679.
† *Journal of the Iron and Steel Institute*, 1888, No. II. p. 252.

**Loss in Fining Iron.**—According to Jacobsson,* the loss in the refinery process formerly did not exceed 13 per cent. At the present time, however, it has increased to 14 to 17 per cent., whilst the consumption of fuel has been lessened by one-third. As a rule the loss is in proportion to the degree of purity demanded for the iron. Grey and white pig iron should always be treated together, and the surfaces should always be previously freed from slag, sand, and other impurities. The proportion of silicon in the iron should not exceed 0·15 per cent., and the fuel should be used in a dry condition.

**Puddling.**—According to a design by Mr. T. M'Sweeney of the Philadelphia Company, an ordinary puddling furnace may be converted into a regenerative furnace burning natural gas. Regenerative chambers are built over the flue and the grate. The ordinary flue is stopped and pipes introduced into the grate for leading in gas. The following meter tests were made with the modified and with an ordinary gas-burning furnace in 1887–88 :—

| Style of Furnace. | No. of Heats. | Material. | | Gas used per 2240 lbs. of Muck Bar while actually working. | Gas used per 2240 lbs. of Muck Bar produced through whole time. |
|---|---|---|---|---|---|
| | | Charged Pig Iron. Lbs. | Produced Muck Bar. Lbs. | | |
| Common A. | 55 | 27,500 | 27,095 | 34,109 | ... |
| " " | 30 | 15,000 | 15,031 | 23,618 | ... |
| Regenerative I. | 55 | 27,500 | 27,525 | 14,829 | 19,079 |
| " " | 55 | 27,500 | 27,125 | 13,529 | ... |
| Common B. | 86 | ... | 42,130 | 30,000 | 58,650 |
| Regenerative J. | 85 | 26,400 | 26,129 | 15,952 | 21,535 |
| " " | 52 | 24,960 | 24,099 | 12,100 | 18,260 |
| Common C. | 55 | 28,875 | 28,725 | ... | 26,958 |
| Regenerative K. | 55 | 28,875 | 28,130 | 13,719 | ... |
| " " | 55 | 28,875 | 27,885 | ... | 14,746 |
| " " | 55 | 28,875 | 27,930 | ... | 13,861 |
| Common D. | 50 | 25,000 | 24,325 | 38,966 | 53,850 |
| " E. | 27 | 20,250 | 20,765 | 24,450 | 35,216 |
| " F. | 55 | 27,500 | 26,888 | 34,583 | 48,144 |
| " G. | 47 | 25,500 | 23,480 | 37,372 | 40,811 |

**Gas-Fired Puddling Furnaces.**—In a paper read at the Vienna Mining Congress, E. Goedicke gave an historical sketch of the gas-fired puddling furnace, discussing at the same time its present metallurgical position. One of the main causes for the gradual abandonment of the old-fashioned form of puddling furnace is due,

* *Wermländska Annaler; Zeitschrift für Angewandte Chemie*, 1889, p. 397.

the author shows, to the large quantity of fuel that is consumed, from 90 to 160 lbs. of coal being required for every 100 lbs. of balls produced, the pig iron used varying from 105 to 112 lbs. By the introduction of gas-firing a considerable saving was effected, as regards the quantity of fuel and pig iron consumed per ton of balls produced. After referring to the satisfactory results obtained with Price's puddling furnace at Woolwich Arsenal, the author describes the Springer furnace. This quadruple furnace was introduced in 1883, and in principle consists in arranging two double-hearthed puddling furnaces in such a manner that, gas-firing being used, the flame passes through the two furnaces one after the other, and then escapes to the regenerators. This arrangement has given excellent results, reference being made to a number of works where these furnaces are in use. The mode of construction and method of working are described in detail.

Experience has shown that, as a rule, the quality of the iron produced by gas-fired puddling furnaces is better than that obtained in ordinary furnaces. The character of the iron produced, however, is greatly dependent on the character of the pig iron used. Thus Styrian charcoal pig iron was found to yield a granular and not a fibrous metal, the reason being that it only contained from 0·1 to 0·2 per cent. of silicon, whilst manganese was present to the extent of from 1·2 to 2·0 per cent. There was not sufficient silicon to insure the slagging-off of the manganese, the consequence being that some of that metal remained in the iron, leading to the formation of a granular structure. When coke pig iron was used this difficulty was not experienced. In the Springer furnace a very high temperature is attainable, and it is found that even charcoal iron, such as that just mentioned, may be made to yield a fibrous metal. The Jüllech and Pietzka furnaces are also described, and the various descriptions of furnaces are illustrated by numerous drawings.

**The Springer Gas Puddling Furnace.**—The inventor of this furnace publishes* detailed drawings of one of a modified form which has been erected at the Königin-Maria Works, Cainsdorf, Saxony, and was fired for the first time at the end of May 1889. The product has reached 10 tons per day of 12 hours, with a consumption of fuel varying from 40 to 50 per cent. of the weight of the iron made, the loss of metal being about 2 per cent. The results of a number of tests are given for the purpose of showing the excellent quality of the product.

* *Stahl und Eisen*, vol. ix. pp. 776–778, 5 illustrations.

**Iron Manufacture in Central Africa.**—According to Mr. F. S. Arnot,* the iron trade caste in the Garenganze tribe are very expert in working iron. The ore is smelted in open trenches filled with iron ore and charcoal, and covered with soft mud. Openings are left at both ends; the fire is lit at one end and blast produced by bellows. The iron is manufactured into hoes, axeheads, spears, knives, chains, and bullets.

* *Iron and Steel Trades Journal*, vol. xxxix. p. 240.

# FORGE AND MILL MACHINERY.

**Comparison of Steam-Hammer and Hydraulic Press Forging.**—A report on this subject was presented by F. Gautier at the Metallurgical Congress in Paris. It was followed by a discussion, in the course of which G. Bresson gave an account of the 750-ton Haswell press that has been in use for some years in the works of the Austrian State Railway, and of a 1200-ton press successfully used at the same works for forging ingots containing 0·01 to 0·02 per cent. of phosphorus. Colonel Bussières pointed out that the forging press was to be preferred to the steam-hammer on account of the rapidity of the execution of the work, the rapidity being four or five times greater with the former than with the latter.

In a lecture at the Stevens Institute of Technology, Prof. C. Sellers has given a comparison between hammers and power presses. The development of the steam-hammer from the ordinary sledge has shown that a blow struck by a light hammer falling through a large distance does not compress the metal so effectually as a heavier hammer falling through a shorter distance, though the momentum is the same in both cases. For forging shafts, the rule is that the weight of the hammer in pounds should be eighty times the diameter of the shaft in inches. The use of such heavy hammers gives trouble with the foundations, and to obviate this the hydraulic press was introduced. The greatest good, as well as the greatest evil, of the press lies in the fact that it is able to hold its pressure and continue its work further than the hammer. Since the pressure is very slow, it is felt evenly through the mass, and the metal is not forged by a succession of actions as under the hammer. It is found that a pressure is required of at least 16,000 lbs. per square inch on the metal to make it fill the die evenly. For riveting, 12,000 to 16,000 lbs. pressure is required; while, if the metal is unconfined, less pressure is required to make it flow.

Experiments have been made with lead cylinders each 3 inches diameter and $3\frac{3}{16}$ inches long, as lead is about equal in resistance to steel at a bright yellow heat.

Experiments with a steam-hammer on lead ingots weighing 3 lbs. and containing 30·73 cubic inches, gave :—

| No. of Blows. | Length in Inches. | Mean Diameter in Inches. | Stroke of Hammer in Inches. | Inch Pounds Developed. | Pressure per Square Inch. Lbs. |
|---|---|---|---|---|---|
| 1 | 2 | 3·64 | 19 | 156,180 | 20,553 |
| 2 | $1\frac{3}{8}$ | 4·38 | $19\frac{5}{8}$ | 161,317 | 20,792 |
| 3 | $1\frac{1}{2}$ | 5·22 | $20\frac{1}{16}$ | 164,660 | 20,792 |
| 4 | $\frac{3}{4}$ | 5·93 | $20\frac{1}{4}$ | 166,455 | 31,501 |
| 5 | $\frac{5}{8}$ | 6·50 | $20\frac{3}{8}$ | 167,482 | 44,362 |

Compression of similar billet in a wheel press to show the action of hydraulic pressure in making the same deformation as each hammer blow had produced :—

| Length in Inches. | Sectional Area. | Gauge Pressure in Pounds per Square Inch. | Total Pressure in Pounds. | Mean Diameter in Inches. | Pressure per Square Inch. Lbs. |
|---|---|---|---|---|---|
| 2 | 10·8 | 1000 | 63,617 | 3·71 | 5890 |
| $1\frac{3}{8}$ | 15·71 | 1600 | 101,787 | 4·47 | 6415 |
| 1 | 21·6 | 2500 | 150,042 | 5·25 | 7383 |
| $\frac{3}{4}$ | 28·8 | 4100 | 260,330 | 6·06 | 8056 |
| $\frac{1}{2}$ | 34·56 | 5000 | 318,085 | 6·63 | 9200 |

The frictional resistances to extension become greater in the latter case, but at no time is the pressure greater than one-third the calculated result of the hammer blows. A similar result was found with hot steel and iron in a mould; 6000 lbs. pressure was required to cause the metal to fill the mould, and 16,000 lbs. to insure the sharp corners being quite filled.

The forging machine can work as rapidly as the hammer. Rapid compression at one stroke may be permitted in compressing ingots for tire making, an effect impossible to attain with the hammer. The power press is self-contained, and will not be broken with sudden shocks, whilst even small hammers must be separate from the anvils.

**Forging Drop Press.**—A new drop power forging press has been constructed by the E. W. Bliss Company, of Brooklyn. The principal feature of the machine is the peculiar shape of the hammer, which is essentially a steel billet placed on end and hammered out at the bottom to give proper support to the die. This construction concentrates the

blow upon the work, gives very long guides for the hammer, and constitutes a very strong and durable arrangement.*

**Hydraulic Press.**—At the ironworks at Croyet-Fourneyron, in France, there has just been constructed for the Lyons Arsenal a hydraulic press which is believed to be the largest in the world. The base plate on which the press rests is a mass of iron weighing 35 tons. The weight of each of the columns supporting the top is 8¼ tons, and the steel top weighs 12 tons.†

**Pneumatic-Hydraulic Forging Press.**—C. Prött ‡ describes a press of this kind of simple construction, by the aid of which any desired pressure may be obtained without difficulty, and with the use of only one pressure cylinder. In other types of press several such cylinders are usually employed when a varying degree of pressure is required. Detailed drawings of the press accompany the description.

**Rolls for Bending Corrugated Plates.**—This machine is the invention of Hohenegger,§ and is the subject of the German patent No. 45,919. On either side of the rolls is a guide roll connected with a slightly curved guide table, and adjustable by worm-gearing. The guide rolls are adjusted level with the top of the bottom roll, and the plate is introduced. By lifting the guide rolls and adjusting the pressure screws, the plate is rolled by repeated reversing until the required radius is obtained. The guide tables allow the plate to be curved to the end. Since the pressure exerted is the same throughout, the curve is regular and the edges of the plates remain even. The inventor is prepared to bend the heaviest sections of corrugated plates into a semicircle.

**Bending Rolls.**—A massive set of bending rolls is illustrated in the *Age of Steel*.‖ The rolls are wrought iron forgings; the two lower rolls are geared together, and the upper one is driven by friction. The upper roll is raised and lowered by power, and one of its bearings can be thrown back to release a ring or flue. The machine is specially adapted for bending the lower plates of boilers, so that seams may be dispensed with.

* *Iron Age*, vol. xliii p. 315, 2 illustrations.
† *The Engineering and Mining Journal*, vol. xlviii. p. 343.
‡ *Stahl und Eisen*, vol. ix. p. 298.
§ *Dingler's polytechnisches Journal*, vol. cclxxii. p. 93.
‖ Vol. lxvi. No. 8, 1 illustration.

**Plate Bender.**—A new form of plate bender is illustrated in *Industries.** It consists of two upright girders, connected together top and bottom with a third girder sliding between them. One of the uprights and the slide carry two inclined faces, over which work friction rollers actuated by a hydraulic cylinder. The slide is thus forced up to the second fixed upright, and as each has a suitable shaped die face, the plate between them is bent as required. The slide is drawn back by a second hydraulic cylinder.

**A New Wire-rolling Machine.**—An improved form of wire-rolling machine, the construction of which is based on that of the machines invented by H. A. Williams some years ago, consists of a series of rolls, each roll being formed with a groove similar to the half section of the desired form. The rolls are arranged at different angles about a common axis in which a guideway, consisting of hollow steel tubes, is provided, so that the grooves forming the passes of the rolls coincide with the guideway. The rolls are adjustable in a circle around the guideway for varying the angles of the different pairs relatively to each other. The rolls are mounted on housing supported on bed-plates, pivoted at one end in the axis of the guideway, and otherwise supported by clamp-bolts, by which they are clamped through a flange to a face-plate of the main frame in which there is a curved slot, allowing the roll-supporting beds to be shifted to obtain the circumferential adjustment. The rolls of each pair are geared together by toothed wheels in the usual way, and one roll is coupled with a driving-shaft, carried in bearings on the bed-plate, and geared by a bevel-wheel with a large compound bevel and spur driver, which revolves around the guideway, and is geared with the main driving-shaft by a smaller spur-wheel. All the rolls are similarly geared to this shaft, with suitable variations in sizes of the wheels to increase the speed of the rolls successively, as the speed of the wire increases by elongation.

In consequence of the great difficulty of practically varying the speeds of the rolls in the same measure as the movements of the wire vary by elongation, and so that the loops of slack between the pairs of rolls in the one case and the overtension in the other may be avoided, a friction device is so arranged that the rolls will compensate for this. Wire of various shapes can be made by this machine.†

* Vol. vii. pp. 28–29.

† *Iron Age*, vol. xliv. p. 1, 4 illustrations.

**Machine for Rolling Wheels.**—A machine for rolling railway wheels consists of an arrangement by which the heated steel blanks, somewhat resembling the wheels in shape, are rolled between six powerful rolls, arranged two at the top, two beneath, and two touching the rim of the wheel. The upper and lower rolls work as two pairs, and form the web of the wheel. By the use of rolls of the required shape any desired form can be given to the web and hub of the wheel. The two outer rolls, which are mounted on vertically-placed axles, form the tread of the wheel as the metal is forced out to them by the action of the two pairs of rolls. By means of a worm and gear mounted on top of the frame, the two upper rolls can be raised or lowered as required while the rolling of the wheel is progressing. The other rolls are fixed in place. It is thought that a pressure of 200 tons to the square inch will produce the best results. The evenness of the pressure results in a smooth surface, and uniformity in the texture of the wheel. It is claimed that the solid rolled steel wheel will have a longer life, will weigh less, and will be cheaper and stronger than the cast iron wheel.*

**Universal Mill.**—A universal mill patented by Mr. J. S. Seaman of Pittsburgh is described with the aid of three figures in the *Engineering and Mining Journal*.† The mill has been successfully employed to roll 8-inch beams.

**Cold Saw Cutting-off Machine.**—A machine made by the Newton Machine Tool Works, Philadelphia, is designed for cutting-off work of any shape. The saw employed can be used for cutting-off square, to an exact angle, or to given lengths. The saw is clamped to the spindle between two collars, the back collar being made with a thread to screw on the end of the spindle. These collars may be unscrewed from the end of the spindle and a large face-cutter screwed on instead. The machine can then be used as an ordinary face-milling machine or rotary planer when not in use as a cutting-off tool.‡

**Hydraulic Crane and Tongs.**—The hydraulic crane and tongs designed by Mr. H. Aiken has recently been introduced at a large number of the more important American steelworks. Drawings of this crane as erected at the slab mill of the Homestead Steelworks appear in the *Iron Age*,§ a full description being also given.

* *Iron Age*, vol. xliv. p. 199, 1 illustration.

† Vol. xlviii. pp. 28–29.

‡ *Iron Age*, vol. xliv. p. 122, 2 illustrations.

§ Vol. xliii. p. 806, 4 illustrations.

**Pneumatic Moulding Machine.**—A new pneumatic method of moulding has been described by Mr. G. Richards.* In the first moulding machines the sand was rammed or pressed by a flat plate, and next the pattern was mechanically withdrawn after the mould was made. Subsequently these methods were combined, and machines were made with flat pressers and withdrawable moulds. The chief difficulty in these machines is to ram the sand uniformly, and experiments were made with divided presser plates, and afterwards india-rubber bags, into which air could be admitted, were tried. These succeeded admirably, and the machine was speedily developed into one with a rotary head. The machine has two heads swivelling on one of the pillars of the machine; the pattern is raised and lowered by levers which can be locked in position. While one head is being rammed up, the box on the other is brought under the sand hopper. The pressing head contains the required number of pressing bags, to which air is admitted at 50 lbs. pressure. In working the machines, five men each are employed, and forty to fifty boxes per hour of eccentric clips, 8 to 12 inches diameter and 2 inches deep, were produced in one trial, and other trials were also given. The total cost of a 16-inch machine, sand conveying apparatus, and boxes, is stated to be £350, and the cost of production 3 pence per box.

* Paper read before the Manchester Association of Engineers, October 26.

# PRODUCTION OF STEEL.

*CONTENTS.*



## I.—*THE OPEN-HEARTH PROCESS.*

**Recent Progress in Dephosphorising Iron.**—At the Metallurgical Congress held in Paris, G. Bresson and E. Gruner presented a report on the progress effected in the dephosphorisation of iron during the last ten years.

The discussion dealt chiefly with the basic open-hearth process. Euverte instanced, as an example of the results obtained with the ore process in France, the products shown in the Paris Exhibition by the Allevard Works (Isère). These were made in an open-hearth from siliceous pig iron, a fifth of the total charge of the furnace consisting of local ore. Remaury gave an account of the results obtained with chrome lining for basic open-hearth furnaces at the Clarence Works. The charge consists of a little more than a ton of ore (calcined Cleveland with about a quarter of Bilbao campanil) and a ton of limestone; to this are added 10 tons of pig iron, 3 tons of scrap iron, and 2 tons of scrap steel with a ton of limestone. The total charge amounts to about 18 tons. This is melted in 4 to 5 hours, the slag that is removed containing half the phosphorus. Ore is then added with or without limestone, according to the ore employed. The entire operation lasts 9½ to 10 hours. The addition of manganese (72 per cent.) does not exceed 0·7 to 0·8 per cent. of the quantity of metal introduced. The steel produced contains 0·02 to 0·04 per cent. of phosphorus, and at most 0·10 per cent. of chromium. At the end of the session, the President, Gillon, called attention to an important modification in the procedure of the basic Bessemer process. The modification

consists in fractioning the slag in two portions, a highly phosphoric slag of great value for agricultural purposes, and a ferruginous slag that may in some cases be advantageously smelted in the blast furnace for basic pig iron. In the basic Bessemer process, three-fourths of the phosphorus is oxidised and driven into the slag during the first two-thirds of the duration of the after-blow, and, during this period, practically no iron is scorified. At the end of the after-blow, however, the iron scorifies rapidly. The method of fractionation based on this observation consists in charging, in the first place, only two-thirds of the total quantity of lime required, and interrupting the after-blow when it is two-thirds over. The slag is then removed, and is found to contain 24 to 25 per cent. of phosphoric anhydride, and hardly any iron. The remaining third of the lime is then placed in the converter, and the after-blow is resumed. A slag is finally obtained containing about 8 per cent. of phosphoric anhydride and 20 to 30 per cent. of ferric oxide.

**Modified Open-Hearth Furnace.**—Mr. L. G. Laureau,* of Philadelphia, describes with the aid of a number of sketch drawings a modification of the Siemens open-hearth. It has the melting chamber completely detached from the regenerators and the gas and air ducts. The melting chamber is oval. The gas and air ports open into the melting chamber, side by side. The cover bricks to the horizontal gas and air ducts outside the furnace can be readily removed, and the ports can be repaired rapidly from the outside without cooling the furnace and regenerators. The roof is held in a wrought iron band and rests upon the melting-chamber walls without being bound into them. It is made high. In furnaces of not over 12 tons capacity two large air and three small gas-ports have proved sufficient. In larger furnaces seven ports are used.

**Manufacture of Open-Hearth Bridge Steel.**—The main difficulty is to secure material which will roll easily without cracking. Sulphur is considered the most harmful impurity in this respect, but Mr. N. W. Shed † has, at Phœnixville, satisfactorily rolled steel containing as high as 0·13 per cent. The steel made there in the 20-ton furnace has the following composition :—

| Carbon. | Manganese. | Sulphur. | Phosphorus. | Silicon. |
|---|---|---|---|---|
| 0·15 to 0·20 | 0·50 to 0·60 | 0·11 to 0·13 | 0·04 to 0·06 | 0·01 to 0·02 |

* *Iron Age*, vol. xliii. p. 960.

† *Transactions of the American Institute of Mining Engineers*, vol. xviii. (Advance proof).

The best heats are made with small amounts of pig iron and ore; if more ore is used, the bottom is cut and the time increased. Up to 50 per cent. of pig iron may be added, but 25 per cent. is better, in which case 10,000 lbs. of pig iron, 30,000 lbs. of steel scrap, and 1000 lbs. of hæmatite are used. The hæmatite is charged in 200 lbs. at a time as soon as the bath is melted. These additions take about an hour, and the heat is then increased till the metal is quiescent after the boil. A test at this time has a bright, coarsely crystalline fracture, showing considerable toughness.

The ferro-manganese in small pieces is put in the ladle while it is being filled, thereby preventing loss of manganese. The steel is top-poured into ingots 15 by 18 inches in section, and weighing 4200 lbs. It works better when poured cool, but hot heats have rolled very well.

The following tests were taken at random and were made on test pieces 8 inches long by ¾ inch diameter:—

| | Tensile Strength. | Reduction of Area. | Elongation. | Carbon. |
|---|---|---|---|---|
| | Lbs. per Square Inch. | Per cent. | Per cent. | Per cent. |
| 1 | 57,160 | 65·3 | 25 | 0·15 |
| 2 | 64,100 | 62·6 | 26¾ | 0·18 |
| 3 | 61,200 | 61·0 | 31¼ | 0·18 |
| 4 | 66,700 | 53·8 | 24½ | 0·21 |
| 5 | 66,700 | 49·3 | 23¾ | 0·19 |
| 6 | 60,000 | 55·1 | 26¼ | 0·15 |
| 7 | 60,800 | 58·7 | 24¼ | 0·13 |
| 8 | 67,500 | 46·3 | 24¼ | 0·16 |
| 9 | 69,260 | 45·4 | 22½ | 0·22 |
| 10 | 60,320 | 54·1 | 30 | 0·17 |

**The Resicza Basic Open-Hearth Works.**—A. Gouvy * describes the manufacture of basic open-hearth steel at the Resicza Works in South Hungary. The furnace used is of the ordinary type. The length of the hearth is 12 feet 3½ inches, the width being 9 feet 10 inches. There are three working doors. The gas enters through three openings, two similar openings serving for the admission of the air. In lining the furnace a layer of magnesite is built up on cooling tubes and forms the ends and sides of the furnace, dolomite being rammed in to form the bed. In the earlier experiments chrome iron ore was used instead of the magnesite, but it was proved to be too rapidly attacked by the slag produced in the working of the furnace. The

* *Stahl und Eisen*, vol. ix. pp. 396-403.

acid roof does not come in contact with the magnesite walls. This magnesite is obtained from Nyustya in Upper Hungary. In composition it resembles the Styrian variety. The furnace charge consists of 3½ tons of grey and mottled pig iron, and 4 tons of scrap, the whole being charged in cold. The amount of limestone added per charge is 0·45 ton. Besides ordinary iron ore, use is made of roughly-formed bricks consisting of a mixture of 25 per cent. of lime and 75 per cent. of hammer-scale. Ferro-manganese is added in small quantity to the metal in the furnace just before tapping. Each charge takes from six to seven hours to work off.

In 1887 a number of experiments were made at the works in order to ascertain the influence on the character of the final product which is exerted by variations in the composition of the charge, but the results did not afford any very definite information. Amongst others, the author gives the results of one such experiment with the analyses of the pig iron and iron ore used, as well as those of the steel and slag produced. The following analyses show the composition of this slag, and the average percentage composition of the slag produced when no ore is added to the charge:—

| | $SiO_2$. | $Al_2O_3$. | CaO. | MgO. | MnO. | FeO. | P. | S. |
|---|---|---|---|---|---|---|---|---|
| Iron ore added . . | 25·20 | 2·13 | 38·85 | 11·77 | 11·95 | 11·45 | 0·37 | trace |
| No ore used . . . | 10·28 | 8·45 | 55·65 | 4·15 | 6·88 | 14·98 | 0·51 | 0·025 |

The metal produced is of very good quality.

## II.—*THE BESSEMER PROCESS.*

**Controlling Converters and Centre Cranes.**—A safety apparatus for automatically controlling Bessemer steel converters and centre cranes has been described by Mr. N. Watts.* The device consists of valves applied to the hydraulic cylinders, which tilt the converter, and may be used when the cylinder is movable or when it is stationary. When water under pressure is admitted to one side of the ram, it acts on a small plunger in a subsidiary cylinder to uncover the inlet port, and this plunger is connected to counterweighted pawls which engage with the pinion on the trunnion of the converter. If by any chance the water supply fails, the small plunger is returned by a counterweight to close the port and prevent escape from the main cylinder. At the

* *Proceedings of the South Wales Institute of Engineers*, vol. xvi. pp. 197–202, with two plates.

same time the pawl engages with the pinion and the converter is held by two means. One of these plungers is placed at each end of the main cylinder, and a third plunger larger than either of them is used in order to force them back to cover the inlet ports on both sides of the main plunger, so that the converter may be held in any position.

The converter is automatically balanced during pouring, &c., and great steadiness is obtained in tilting by a further feature of the invention. By an arrangement of levers, the pinion acts on one or other of the escape valves, arranged so that when the vessel is discharged the device ceases to act, and the vessel can be lowered for cleansing. The device for cranes is similar to that described above, but does not require to be duplicated. The apparatus has been applied to a converter at Ebbw Vale with success.

**The Rothe Erde Steelworks.**—In their recent German tour the American engineers visited the Rothe Erde Works. At these works there are three basic Bessemer converters placed side by side, their axes converging towards the centre of the pit. The pit is relatively deep, and is served by one large and twelve smaller cranes. Behind the converters are three cupolas, each nearly 10 feet in inside diameter, but one of them is sufficient to melt all the iron required. The weekly production of basic Bessemer steel at these works is from 3000 to 3500 tons. The iron ore of the adjacent districts contains from 1 to 1·5 per cent. of phosphorus; ores richer in phosphorus have therefore to be imported. The converters are 9 feet 10 inches in internal diameter, and are lined up to about 7 feet 2 inches. They have a capacity of 12 tons, and yield about 10½ tons of ingots. The calcined dolomite used as lining is mixed for that purpose with 7 per cent. of boiled tar, which is raised to the mixing tank by a Körting injector. The bottom is 2 feet thick, and it contains eighty-four ¾-inch tuyere holes. The bottoms are rammed by hand, baked, and then lifted into place by a hydraulic ram, the joint being made by pouring in a few buckets of tar. At its maximum this joint is 0·58 inch thick. The life of a bottom is stated to be from 20 to 22 blows. The body of the converter is lined from the bottom upwards, and first with six courses of 9·8 inch basic brick. The rest of the lining is rammed in in place, over a sectional iron form. It stands about 150 blows.

A new 37½-inch reversing blowing mill is in course of erection, an

important feature being that the whole of the train and tables is commanded by a 10-ton overhead travelling crane.

In 1888 the Rothe Erde Works produced 141,486 tons of basic ingots, and 11,746 tons of puddled blooms. The rolling mill turned out 152,254 metric tons of merchantable goods, and 1150 tons of drawn wire and wire nails. The pig iron consumed amounted to 185,913 tons, the consumption of coal being 98,529 tons, of coke 19,205 tons, of lime 26,519 tons, and of limestone 3882 tons. About 2300 workpeople were employed; the sum paid as wages was £110,533.*

* *Iron Age*, vol. xliv. p. 120.

# FURTHER TREATMENT OF IRON AND STEEL.

**Treatment of Steel by Hydraulic Pressure.**—The defects in ordinary cast ingots are ascribed by Mr. W. H. Greenwood * to the occlusion of gases on solidification, to the holes produced by contraction after the outer skin has solidified, and to the radial acicular structure. The combined effect of these defects in large castings necessitates the rejection of some 30 per cent. from the head, and causes 10 to 20 per cent. waste in turning and finishing.

Several methods for compressing steel, such as the use of explosives, steam, or carbonic anhydride acting directly, are noticed by the author, and their failure ascribed to mechanical imperfection. The history of hydraulic compression is then traced from its first suggestion in 1856, and early forms of plant are described. The author then proceeds to describe a 10,000-ton press which he has recently erected in Russia. This press is on the lines of the Whitworth patent of 1874; it has four screwed columns of 16 inches diameter, and one hydraulic pressing cylinder of 50 inches diameter. For working the press, an accumulator giving a pressure of 2 tons to the square inch is employed to effect the rapid movements of the head, cranes, and other parts. The prepared mould is placed on the lift, filled from a ladle, raised and pushed forward by a horizontal ram to the carriage beneath the press. The head, weighing 50 tons, then descends till the plunger enters the metal, after which it is locked in position, and the cylinder comes into play.

The pressing is continued as long as there is any shortening. The pressure ranges from 4 to 12 tons per square inch of metal, and is continued for forty-five minutes to three or four hours. The contraction usually amounts to 1½ inch per foot. The specific gravity of steel containing 0·54 per cent. of carbon was increased from 7·8542 to 7·8795, and the density of the ingot as a whole is 8 to 12 per cent. higher than that of an uncompressed ingot.

* *Minutes of Proceedings of the Institute of Civil Engineers*, vol. xcviii. pp. 83–203.

In order to compare the behaviour of the metal with and without compression, two 8-ton ingots were cast, and a slab 4·75 inches thick, the full length and bread of the ingot, was cut from each. The pressed ingot was quite round on both faces, and gave 98 test pieces, while only 70 could be cut from the other. Cylindrical test pieces 4 inches long cut from or across the axis were tested with the following results:—

| | Elastic Limit in Tons per Square Inch. | Ultimate Breaking Strength in Tons per Square Inch. | Contraction of Area at Point of Fracture. | Elongation in 4 Inches. |
|---|---|---|---|---|
| | | | Per cent. | Per cent. |
| Unpressed ingot . | 11·11 | 29·18 | 4·41 | 8·76 |
| Pressed ingot . . | 11·45 | 29·53 | 7·90 | 12·51 |
| Unpressed ingot . | 11·43 | 28·04 | 3·61 | 7·91 |
| Pressed ingot . . | 12·38 | 30·07 | 7·57 | 12·74 |

The first two lines show the mean of the test pieces cut longitudinally, and the second, those cut transversely from the ingot. The pressed ingot gave its greatest breaking strength near the top, contrary to the unpressed ingot, but in both the elongation fell away as the top of the ingot was approached, slowly in the pressed ingot, but very rapidly in the other at points above its middle. The elastic limit and breaking strength increased in both from the centre outwards, and in the pressed ingot the ductility similarly increased, but was about constant in the other. From these tests the author concludes that the pressed ingot is weakest along its axis, and is regularly distributed.

**The Gjers Soaking Pit.**—Mr. W. F. Durfee * states that the quantities of steel which passed through the Gjers soaking pit in 1887 and 1888 was as shown in the following table:—

| | 1887. | 1888. |
|---|---|---|
| | Tons. | Tons. |
| Great Britain . . . | 237,546 | 257,335 |
| Germany . . . . | 153,454 | 227,020 |
| Austria . . . . . | 90,000 | 95,000 |
| Belgium . . . . . | 68,162 | 67,377 |
| France . . . . . | 8223 | 22,558 |
| Sweden . . . . . | 4348 | 4,578 |
| United States . . . | ... | 38,660 |
| Totals . | 561,733 | 712,528 |

* *The Iron and Steel Bulletin*, through the *Iron Age*, vol. xliv. p. 246.

**Casting Steel Ingots.**—Mr. T. S. Crane* describes the method used for casting and compressing steel ingots devised by Mr. J. B. D'A. Boulton. In this process the ingot moulds are made without bottoms, and are superposed one on the other. They are filled successively, and the shrinkage in each ingot is fed by the fluid metal in the one immediately above. An asbestos washer with a small aperture is placed between each ingot, so that the bottom one can easily be removed. An ingot cast by this process and split open is shown to be perfectly sound.

Full drawings and description of the plant are given by the author. The moulds are divided longitudinally into two halves, and are held together and guided downwards by guides held together by springs. The moulds are placed in position by hydraulically actuated tongs. The bottom mould passes into a transverse hydraulic cylinder, which shears off the ingot, which drops when released from a spring-holding dog. The moulds are removed from the ingot and sent to the top of the apparatus by a rachet-ladder arrangement in which a series of spring pawls on the guide-way drop into notches on the mould as they are pushed up by the introduction of a fresh one.

At the Bergen Steelworks, where the apparatus has been in constant use since December 1887, ingots 4 inches square are cast regularly at the rate of one a minute when the heat is ready. One man is required to operate the hydraulic gear, and the ordinary workmen to pour the metal.

**Electric Welding of a Wire Cable.**—Electric welding-machines are being erected by the Trenton Iron Company, New Jersey. The machines are of the latest type, manufactured by the Thomson Electric Welding Company. The cables to be welded are 1¼ inch in diameter, and are composed of four successive layers of wires, with a single fine round wire for a core. The wires are placed in concentric rings, the outside one of which is composed of 24 cold-drawn wires of low-carbon steel, each wire fitting exactly, and locking with those adjacent to it; the next ring consists of 19 similar wires. The third ring consists of 12 round wires of larger diameter than the round wires forming the fourth or inner circle. The core is a round wire of about the same diameter. Each layer of wires has a direction of twist along the length of the cable, but opposite to the direction of twist of the next layer of

* *American Institute of Mechanical Engineers; The Engineering and Mining Journal*, vol. xlvii. pp. 456–457.

wires, and the angle of twist of each layer is different from that of any other layer.

It is evident that the welding of a cable of this form is a matter of some difficulty. The following conditions had to be met:—1. It was necessary to provide means for preventing the separate wires from fraying outwards when the longitudinal pressure used in the welding was applied. 2. It was necessary that the cable should be gripped in such a manner as to prevent sliding movements of the wires with relation to each other. 3. An unusual preparation of the ends had to be made in order to accomplish, at least approximately, the separate welding of the wires composing the cable, so that in bending around a sheave the load strains might be distributed at this point in the same manner as at any other point. 4. It was necessary to have the ends of the wires at one terminal as nearly as possible in line with the ends of those in the other terminal. In order to prevent the fraying and expanding actions above mentioned, it is found necessary to shrink mild steel or iron sleeves or collars tightly upon the cable close to the ends (about $\frac{1}{16}$ inch therefrom), and this arrangement is found effective in preventing the wires from sliding over each other when the pressure is applied in welding; but it also prevents the separate welding of the wires forming the cable, a difficulty overcome by special preparation of the ends of the cable—by cutting grooves between the ends of the contiguous layers of wires, forming thereby a series of concentric circular grooves. This permits of a definite amount of "upset" of softened metal at the end of each wire, which must be allowed for, it being caused by the endwise pressure used in forcing the pieces together when the welding temperature is reached, and permitting also the welding together of the wires forming the cable. The ends of the separate wires can be brought exactly opposite each other by the exercise of ordinary care upon the part of the operator of the machine.

Experiments made with a view to determine the tensile strength of the welds produced, showed that the maximum tensile strength of the cable was 67,000 lbs. per square inch before annealing, and about 50,500 lbs. after heating to a temperature slightly below a welding heat, and then allowing the metal to cool slowly. The tensile strength of the welded cable averaged over 50,000 lbs., some specimens resisting a stress of as much as 53,000 or 54,000 lbs. per square inch. The ratio of elastic limit to ultimate tensile strength is about the same in unwelded as in welded specimens. Severe bending and twisting

tests give equally good results, it being possible to bend the cable at the weld backwards and forwards many times through an angle of 180°.

**Sand Core Process.**—A recently published report by Mr. G. E. Betton * deals with a process in which a sand core is included in the metal, and the composite material is afterwards rolled or forged. For casting ingots, &c., a box of sheet iron filled with fine sand or finely powdered quartz is placed in the mould, and the melted metal is cast round it. For wrought metal, bars of iron are placed round the sand receptacle, and heated to welding point, after which the pile is worked in the usual manner. It is stated that ingots can be rolled into plates and sheets, or drawn down into rods of almost any thickness. The sand core is found evenly distributed, and does not interfere with the working. This composite material can be used for rails, axles, shafting, structural columns, armour plates, and generally for purposes where great stiffness, combined with lightness, is required. The results of a test made at the Watertown Arsenal are given. In this case, a column 4 feet long by $4\frac{1}{4}$ inches diameter, with a $2\frac{5}{8}$-inch sand core, endured a longitudinal stress of 228,000 lbs. without starting the scale, and 344,000 lbs. with a deflection of $1\frac{1}{2}$ inch.

**Tool Works.**—A description is given in the *Age of Steel* † of the Niles Tool Works, at Hamilton, Ohio. The erecting shop is the centre of the main machine-room, which is 116 feet wide in the clear, by 400 feet long. It is spanned by a 20-ton power crane. On each side of the erecting shop is a machine-room, 40 feet wide. The smaller planers, &c., are placed in a room 40 by 200 feet. Among the large tools are a planer which planes 8 feet square by 32 feet in length, a 72 by 72 by 24 foot planer, a 60 by 60 by 32 planer, an 8-foot and a 10-foot boring and turning mill, and a horizontal boring, drilling, and milling machine, taking work 6 feet high by 20 feet long. The front buildings are 375 feet by 44 feet and 2 stories high, containing lathes on the ground floor, whilst in the second story are the offices, drawing room, and milling screw and gear-cutting machines.

The foundry consists of three apartments, 140 by 45 feet, 146 by 60 feet, and 120 by 55 feet respectively, served by two overhead and six gib cranes. There are three cupolas with combined capacity of 30 tons per hour. The blacksmith's shop is 120 by 55 feet, and is provided with

* *Iron*, vol. xxxiv. p. 32.
† Vol. lxvi. No. 3, 2 illustrations.

cranes, steam-hammers, and case-hardening furnace. The pattern store is fire-proof. The whole of the works is lighted by electricity, and heated by hot air or steam. Crude oil is used as fuel for the two batteries of boilers and the core ovens. A compound Corliss engine of 250 horse-power furnishes power for the entire works except the foundry blower. Amongst the machines being erected were two sets of 16-foot rolls and one set of 22-foot rolls, each roll for the latter weighing 35 tons, and the whole machine weighing 100 tons.

**Annealing Box.**—An annealing box has been designed by Mr. W. H. Bailey * to prevent warping, and to protect the contents from air. The side plates are braced and supported by T or angle irons; other angle irons support the bottom plate. The cover rests on angle irons bolted or riveted inside the box, and is suitably strengthened. A layer of sand can be placed on the flat top. This box will hold more than one with a round top, and it is also claimed that it will last longer and is cheaper.

**Cleansing Castings by Sand Blast.**—Two forms of apparatus for cleaning castings by means of the sand blast have recently been devised.† In one form, the casting is suspended and moved about in front of a horizontal blast, and in the second form the casting is stationary, whilst the apparatus can be moved so as to direct the blast in any desired direction. The required velocity is preferably given to the sand by a jet of steam, which is met on its way by a counter current of air for the purpose of removing the steam and of drying the sand. The weight of the sand carries it forward, and it reaches the work in a cool, dry condition.

**Detection of Defective Welds in Pipes.**—In consequence of information published in the English technical journals, Lentz ‡ has endeavoured to employ the magnetic needle for the detection of defective welds, and has found that such places can be distinctly observed by deflections of the needle. The investigation is, however, considerably interfered with by the magnetism of the pipes; and as it is therefore necessary to de-magnetise the pipe by hammering, the examination becomes tedious. It is advisable, before the pipes are

* *American Manufacturer*, vol. xlv. No. 4.
† *Engineering*, vol. xlviii. p. 527.
‡ *Zeitschrift des Vereines deutscher Ingenieure*, vol. xxxiii. p. 785.

examined, to leave them for some time lying in an east and west direction.

**Automatic Vertical Tapping Machine.**—A vertical tapping machine, designed for tapping nuts from $\frac{3}{4}$ inch to 2 inches in diameter, has been designed by the National Machinery Company, Ohio, to do away with the labour of raising and lowering the heavy tapping spindles. At the upper end of each of the tap spindles is a 3-inch pitch double-threaded screw, surmounted by a disc, which is loose on the spindle. At the top of a central column around which the tap spindles are arranged is a sleeve, which is prevented from rotating with the column by a spring on a frame supporting the top of the column. This sleeve carries a spiral rack and flat bench, followed by an incline. As each tap spindle rotates into position its screw engages in the spiral rack, and is elevated. When it has reached its highest position the disc on the top of the shaft passes over it and down the incline, the spindle dropping down and the tap entering the nut, which had been automatically placed beneath it.*

**MacCoy's Pneumatic Tool.**—The principle underlying the construction of this tool is similar to that employed in the construction of rock-drills; but in the mechanical details it varies widely. The tool consists of a cylinder within which is a reciprocating piston which acts as a hammer, delivering its blows on a detached tool-holder projecting through the lower end of the cylinder. The most important characteristic of the tool is the high rate of speed, estimated as high as 15,000 strokes per minute, and the automatic operation of the hammer. The tool is operated by either compressed air or steam, under a pressure of about 40 lbs.

The piston is not connected to the tool-holder, but strikes it as would a hammer. The upper or inner end of the tool-holder has an enlarged head, which fits loosely in the head of the working cylinder, and receives the blows of the piston. As the latter rises and falls in the cylinder it closes the ports, and thereby incloses a portion of the air, which forms an elastic cushion, and relieves the tool of the shock which would otherwise result at the end of each stroke. The hammer has a very short stroke, and as there is an appreciable difference in the diameters of the hammer and its metallic cylinder, an air chamber is formed around the hammer, which reduces the friction to such an extent that

* *Iron Age*, vol. xliii. p. 425, 2 illustrations.

but little power is here lost, the wear is exceedingly small, and the remarkable rapidity above-mentioned is made possible.*

**Universal Milling Machine.**—The *Iron Age* † publishes detailed illustrations of a universal and automatic milling machine, designed by L. H. Nash. It was specially intended for the purpose of cutting the gears and pinions used in a water-meter, a work in which considerable accuracy was necessary. The machine described has cut over 100,000 gears a year for over seven years, and the repairs have been but slight.

A number of universal milling machine attachments are also described and illustrated.‡

**Pipe Cutting and Threading Machine.**—A new machine of this class, manufactured at Bridgeport, Connecticut, is arranged to cut off and thread all sizes of wrought iron pipe, from 2½ to 12 inches in diameter. The die-carrying gear is supported in a casing with the pinion embedded in its side. On the back of the gear is placed a lead screw of the same number of threads to the inch as the pipe to be cut, which engages with the brass lead blocks on the sides of the shell, and which work out or in by eccentrics. Thus as the gear revolves in the shell it is drawn into it by the lead screw, and the dies are brought on to the pipe. The description is accompanied by an illustration showing the general arrangement of the machine.§

A similar machine, manufactured at St. Louis, Montana, is so arranged that the dies throw open far enough to allow the pipe to pass through to the cutting-off tool without opening the die head or sliding it on one side. The machine is supplied with the Peerless die head, reversed so as to place the dies next to the gripping chuck. This latter is of great strength, and has three independent jaws which are graduated to the different sizes of pipe.||

**Riveting Machines.**—Two forms of riveting machines are illustrated in the *Iron Age*.¶ They are of American construction. One is an elastic rotary blow machine in which the hammer rod, suspended by springs and confined air within the cylinder, partakes of its reciprocating motion, and produces a sharp, quick blow. Both hands of the

* *Iron Age*, vol. xlix. p. 242, with detailed drawings.

† Vol. xliii. p. 501, 3 illustrations.

‡ *Iron Age*, vol. xliii. p. 428, 6 illustrations.

§ *Ibid.*, vol. xliii. p. 951.

|| *Ibid.*, vol. xliv. p. 48, 1 illustration.

¶ Vol. xliii. p. 313.

operator are free. The second machine illustrated is a modification of that just described.

**A New Shaping Machine.**—A machine of this kind is described and illustrated in the *Iron Age.** It is self-adjustable, and has two speeds, one for cast iron and the other for steel. The ram is long, has a quick return, and is actuated by a powerful train of heavy gearing made in duplicate, the under surface of the ram being formed with two racks, with which the driving gears engage. The ram head is graduated. An important feature is the quickness of the change in direction of the movement of the ram, which will work up to a line and reverse in less than $\frac{1}{4}$ inch.

**Drilling Machines.**—The Keyston radial drill will take in a pulley up to 4 feet in diameter, and will bore small cylinders and similar work. The screw will feed 14 inches and has an adjustable automatic feed. The circular table is 24 inches in diameter and is bored to receive bushes for boring bars; it can be raised or lowered without being turned around. The square tilting table slips in the slotted side of the bed and can be quickly removed. The drill illustrated in the *Iron Age* † has a radius of 48 inches, and will drill to the centre of an 80-inch circle. The column is 12 inches in diameter and is 6 feet high.

The Leeds drilling machine is designed to work on or from a drill press. It is mounted on the frame, and is driven direct from the drill press spindle. This machine does away with the ratchet worked by hand, and is capable of drilling with great speed.‡

**Machine for Making Wire Rope.**—This machine forms a continuous rope by a series of steps which involve the laying up of wires to form the strand cores, then the laying of the wires about these cores to form the strands, and finally the laying up of the strands about a central core to form the completed rope. The peculiarity of this machine lies in the power-transmitting mechanism for rotating the central shaft and imparting rotary motion to the turn-tables, the invention of H. Root.§ At different heights about a hollow vertical shaft are platforms the number of which depends upon the size of the

* Vol. xliii. pp. 309–311, 6 illustrations. † Vol. xliii. p. 314, 5 illustrations

‡ *Iron Age*, vol. xliv. p. 283, with illustrations. § *Ibid.*, p. 316.

strands to be made. To each of a series of turn-tables is imparted a rotary motion on its own centre in addition to the primary revolution which all have about the central shaft. Upon each turn-table are a spool and frame carrying the wire. These frames are carried by shafts mounted in the turn-tables and are rotated in order to keep the face of the wires always in the same direction to lay them up straight. The parts above described and their movements are those common to this class of machines, and it is evident that by the rotation of the turn-tables on the lower platform about their own axes the wires are laid up to form strand cores. The rotation of the turn-tables on the upper platform lays up a series of wires around these cores to form strands. By the revolution of all the turn-tables about the central shaft the strands are laid up to form the rope, and by the rotation of the spool-frames on their own shafts the wires are laid up straight in the strands.

**New Method of Handling Ingots.**—Messrs. C. Law and C. E. Hall* have designed an arrangement for casting heavy steel ingots and of handling the moulds and ingots preparatory to the reheating and rolling, whereby the danger to the workmen, the excessive heat to which they are exposed, and much of the labour and expense incident to the old plant may be avoided, and the ingots cast and handled with great speed and facility.

In this plant, no pit or pouring-ladle being employed, the molten steel is poured directly from the converter into the moulds, a bowl or runner being used to properly guide the stream of molten metal from the pouring-hole or lip of the converter into the mould. The moulds are mounted upon a movable carriage travelling upon a track extending under the converter, the carriage being moved to bring the moulds one after another in place under the converter by the aid of a hydraulic ram. As each mould is filled the converter is tipped up and the car is moved forward to bring another mould into position, thus avoiding the loss of metal which in the old process adheres to the sides and surface of the ladle. The pouring of the molten steel directly from the converter into the moulds is done preferably through a pouring-hole near the mouth of the converter.

After the entire charge of molten steel in the converter has been poured directly from the converter into the series of moulds on the movable carriage, the mould-carriage is removed from the converter. As soon as the steel becomes set, the moulds are turned from their

* *Iron Age*, vol. xliv. p. 237.

erect position into an approximately horizontal one, and the ingot is pushed through the mould, and is at the same time, and by this same stripping operation, delivered in a horizontal position upon another carriage. The ingots, whilst still hot, are by this second carriage conveyed directly to the furnace of the rail-rolling department, where they are reheated preparatory to the rolling operation.

The moulds are preferably hinged to the bed of the carriage upon which they are mounted, and are turned into a horizontal position by a hydraulic ram, the piston of which is furnished with hooks or grappling devices for engaging the upper end of the mould. This hydraulic ram is mounted in an inclined position. The means employed for pushing the ingot out of the mould on to the furnace-carriage is a similar hydraulic ram mounted in a horizontal position. After the ingot is thus extracted from the mould and delivered upon the furnace-carriage, the moulds are again lifted or turned into their upright position on the carriage by means of the same hydraulic ram by which they were lowered. The number of moulds upon each truck may be varied, but a series of ten moulds upon two cars coupled together and operated as one will receive the entire charge of the converter.

By this arrangement it is believed that it will prove possible to dispense with the labour of the pit men, the pouring-ladle, the cranes for receiving and handling the pouring-ladle, the pit, the lifting-cranes for removing the ingots and moulds from the pit and replacing them, and, further, that the ingots may be delivered to the rail-rolling furnace within a period of about ten minutes from the time the steel is poured from the converter into the mould.

**Tin Plates.**—The tin plate works at Hennebout,* in the department of Morbihan, manufacture about 12,000 tons yearly. The works were established in 1860 with a first production of 750 tons. Soft steel is manufactured by two open-hearth furnaces, each producing 22 tons in twenty-four hours. The steel is cast into conical ingot moulds, 3 feet high, placed in fours and connected at the bottom. A steam-hammer is used to cut the ingots in two. They are then rolled into bars 4 inches wide, and 0·4 inch thick, and cut into lengths of 8 to 12 inches. These plates are rolled and folded successively into eights, which are separated while hot. Pickling and tinning operations are conducted in the usual manner, chopped rice straw being used for cleaning the greasy plates. The works employ about 700 hands and 1000 horse-power, of which one quarter is supplied by a turbine.

* *La Nature*; *Iron*, vol. xxxiv. pp. 52–53.

**Nails from Tin Scrap.**—Nails made by pressure from tin scrap were first invented by Mr. G. H. Parker, and Mr. O. Smith,* who has been associated with him, describes the development of the manufacture. In the first attempt, approximately rectangular blanks were corrugated, and then the corrugations crushed together, the heading being performed in a separate machine. One machine was then devised to perform all these operations automatically, but it was found that there was a tendency to split in the tightly folded corrugations. It was then found better to crush up the blanks edgewise into any form they chose to assume, and in the latest machine irregular scrap can be fed by the operator, and the finished nails automatically delivered at the rate of thirty to ninety nails per minute. It was also attempted to coil the blank, but this is too expensive. The best form has a square taper shank, similar to a cut nail. The nails do not rust much, and will take solder.

**Horse-Shoe Nail Iron.**—H. Wedding † shows that the ingot iron from the Peine Works is as well adapted for the manufacture of horseshoe nails as is Swedish charcoal iron.

**Rail Sections.**—The ability of a rail to resist all strains to which it is subjected, depends quite as much on the character of the metal as on the form of the section. Consequently, in designing the section, ample allowance must be made for the varying qualities of the material. Mr. R. W. Hunt ‡ returns to this subject, and again points out the pernicious effect of rolling at high temperatures. Earlier rails certainly did not owe their excellent wearing capabilities to their composition, as the carbon varied from 0·24 to 0·70 per cent., silicon from 0·032 to 0·306, phosphorus from 0·077 to 0·156, and sulphur from 0·050 to 0·181 per cent. in some that the author examined.

The great increase in the load on the wheel flanges calls for a broader head on the rail, and a heavier section generally, but, at the same time, the railroad engineer tries to secure this with the smallest outlay. The New York Central and Hudson River Railroad are relaying the whole Hudson River section with the Dudley rail of 80 lbs. per yard. The author's proposed sections have, however, departed from this design and approximate to that in use on the

* *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 495–498.

† *Verhandlungen des Vereins zur Beförderung des Gewerbefleisses*, 1889, p. 90.

‡ *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 778–785.

Michigan Central Railway. Eight forms of sections are shown, varying in weight from 60 to 90 lbs., and including two 75-lb. rails, one with a broad, the other with a narrower flange. The characteristics of these sections are wide and comparatively shallow heads, strong webs and flanges, with thick edges. The metal is distributed to avoid cooling strains, and so to minimise the cold straightening required.

M. C. Walckenaer * gives illustrations, and particulars of some steel rails showing abnormal deterioration due to damp, whereby the head in one case, at least, has almost been removed.

The results of some experiments to determine the durability of rails as affected by the hardness of the metal are given by M. J. W. Post.† In 1882 a large number of sample rails were laid down in the Netherlands, with tensile strengths above 38 tons per square inch for the harder rails, and 33 tons per square inch for the softer rails. Careful analyses and breaking tests were made of the metal in each case. The averages of sixteen rails from four different blows are given, two above and two below the limits mentioned above, and it is found that the waste of the soft rails exceeded that of the hard by 27 per cent., and seems to be approximately inversely proportional to the breaking load.

M. A. Hallopean ‡ describes in detail the qualities of steel required for rails and other parts of the permanent way, such as fish plates, chairs, bolts, &c., with details of manufacture and tests to which they are subjected.

A committee appointed four years ago by the American Society of Civil Engineers to report on the proper relation to each other of the sections of rails and wheels, have recently presented their report. In the first place they recommend a 12-inch top radius as a standard for rail sections of all weights. They next recommend a head broad relatively to the depth for sections of all weights, care being taken not to go too far in either dimension, especially in very large or very small sections, or to endanger the flange cutting into the joint. The third suggestion is the use of $\frac{1}{4}$-inch corner radius as a standard for all sections. They also recommend a $\frac{1}{16}$-inch lower corner radius for the head as a standard for all sections; further, that starting from a sufficient base width of head to give ample bearing for the joint, or to conform to the first-mentioned recommendation, the sides should be

* *Revue Générale des Chemins de Fer*, 1889, No. 2, pp. 153–155, with plate.
† *Ibid.*, pp. 156–160. ‡ *Ibid.*, pp. 93–152.

carried up vertically as a standard for all sections. These recommendations refer generally to sections of all weights.

In the concluding remarks of the report, the committee add that with regard to their recommendations they see no reason why they will not give an equally favourable section for either curves or tangents, and either for angle-bar joints or for any form of base-support joint. The committee does not think an inward flare for such joints to be desirable.

A new section of rail weighing 94½ lbs. per yard is being introduced on the Paris, Lyons, and Mediterranean Railway in place of the old rail of 78½ lbs. per yard, which has been in use since the introduction of steel on this line in 1868. The breadth of the head has been increased from 2·36 to 2·60 inches; the height and thickness of the flange have also been increased. Dimensional drawings of the rail and fish plate are given in *Le Génie Civil.**

R. M. Daelen † describes a new rail section, the rail stem being made hollow. By using a ⊥-shaped fish-plate, great resistance to crushing stress may be obtained. The base of the rail is very broad. The author compares this section with the Sandberg Goliath rail, and he shows that the division of the metal in the two rails is as follows:—

| | Goliath Rail. | New Section. |
|---|---|---|
| | Per cent. | Per cent. |
| Head . . . . . . | 43·5 | 37·0 |
| Stem . . . . . . | 23·9 | 28·0 |
| Foot . . . . . . | 32·6 | 35·0 |

The description is accompanied by illustrations showing the general construction of the new rail.

Kirdorf ‡ controverts the statement that basic steel rails, after being in use for some time, are rapidly worn away. Mild steel, he shows, is better adapted for rails than hard.

**Railway Axles.**—A committee was appointed by the Government of South Australia to report on the tests for railway axles.§ The following tests were recommended for iron axles:—The average of all the test pieces taken from any one axle must reach 22 tons per square inch

* Vol. xv. p. 148. † *Stahl und Eisen*, vol. ix. p. 836.
‡ *Zeitschrift des Vereines deutscher Ingenieure*, 1889, p. 849.
§ *Iron and Steel Trades Journal*, vol. xlv. p. 333.

tensile strength, and 22 per cent. elongation; but a minimum of 21½ tons tensile strength and 19 per cent. elongation will be admitted, provided the foregoing average is reached. The test pieces should be cut from the wheel seat of the axle, and from as near the outside skin as possible. The Board recommend the Government to adopt steel axles in place of iron, seeing that this is the only colony which has not yet abandoned the use of iron axles.

**Fracture of Railway Tires.**—The number of fractures of railway tires in 1888 on German railways having a working length of 24,090 miles was 4577, this number comparing with that of the previous year in the ratio of 87 to 70. In the three months January, February, and March, 63·1 per cent. of the total number of fractures took place. An examination of the fractured tires showed that the material giving the worst results in this respect was puddled steel, next to this came malleable iron, whilst better results were obtained with steel tires.*

**Steel Cross-Ties.**—I. Muskewitz † describes with the aid of several illustrations the Schülke system of metal cross-ties, as well as the mode of attachment of the rails. The method is stated to possess numerous advantages.

**Metal Sleepers.**—A form of iron sleeper is shown in the *Indian Engineer.*‡ It consists of a cast plate strengthened by webs. These plates are placed under the rails and secured by a tie bar, which is notched under the rail base and bears against it on one side. On the other side of the rail a key bears against the flange and tightens it up against the tie bar and sleeper jaw.

The greater number of systems of metal sleepers present the same defects, insufficient resistance to transverse shocks and difficulty of solid attachment by means of keys, bolts, and rivets. Where the traffic is large, the fastenings fail. To obviate these defects a new traverse sleeper has been designed for the double-headed rails used on the West of France Railway. The sleeper is a steel ∩ section about 8 inches wide, 3½ inches deep, and 8½ feet long. The chairs are cast on the sleepers and embrace the sides for a distance of 4½ inches, so that they grip firmly when the metal contracts on cooling. For addi-

* *Centralblatt der Bauverwaltung* through *Stahl und Eisen*, vol. ix. p. 631.
† *Stahl und Eisen*, vol. ix. p. 768.
‡ Vol. vii. p. 353.

tional security a notch or groove is made in the sides of the sleeper, into which the metal of the chair projects.

The weight and cost of each sleeper with its two chairs is :—

| | Lbs. | s. | d. |
|---|---|---|---|
| Steel . . . . | 132 | 7 | 1½ |
| Cast iron . . . . | 110 | 3 | 11½ |
| | 242 | 11 | 1 |

**Ingot Metal for Boilers.**—E. Cornut * discusses the value of steel for the purposes of boiler construction. In order to more forcibly show improvement in metallurgical processes and the change in opinion which has taken place of recent years as to the character of the metal to be employed, he gives in tabular form a series of trade requirements from 1855 to the present time. In the former year it was stipulated that the tensile strength should be 51 tons per square inch with an elongation of 9 per cent. on 7·87 inches. In 1887 the author formulated the following specification: tensile strength not to exceed 25·4 tons, with a minimum elongation of 28 per cent. on a test piece of the length mentioned above. The reason for the adoption in the earlier years of steel of the character mentioned was due to the spread of the Bessemer process, which, at that time, only admitted of the production of a steel of this character. Not until 1865, when manganese came into use, was it possible to obtain a more suitable material. At the present time metal of the required character can be produced—either the Bessemer or open-hearth process is available—and the author gives particulars as to the character of the metal produced at the more important French works, including those of Denain, Anzin, and Creusot. With reference to the relative cost of ingot metal and weld iron boilers, the author shows that in 1882 the former were in France 50 per cent. the dearer, but that by 1886, whilst weld iron diminished 30 per cent. in value, ingot metal decreased in value by 49 per cent., the consequence being that with slightly diminished thickness the ingot metal boiler was actually the cheaper of the two by about 5 per cent. Experience gained at Creusot has led that works to employ a metal containing scarcely any silicon and but little phosphorus or carbon, and showing an elongation of 33 per cent. on 7·87 inches.

In order to ascertain whether weld iron and ingot metal plates possessed the same physical properties throughout their mass, the author made a lengthened series of experiments which proved this to be the case as regards ingot metal, whether hardened or annealed.

* *Annales Industrielles*, 1888–89.

By annealing the tensile strength was diminished by about 3 per cent., whilst hardening increased it by 21 per cent.; the elongation being in the one case increased by 5 per cent., and in the other diminished by about 30. Weld iron plates, on the other hand, were found to vary greatly in their quality when test pieces were cut in different directions. In conclusion, the author observes that as the thickness of ingot metal boiler-plates may be about 13 per cent. less than that of weld iron plates, the cost of boilers made with the two varieties of metal is about the same, the advantages in other respects resting with the ingot metal.

**Defects in Boilers.**—An illustration is given in the *Locomotive* * of a corroded boiler-plate which had been so weakened that the blow-off was pulled out by hand. In one place the plate was eaten right through. Another illustration is given of a plate on which was a small blister which was trimmed up with a cold chisel. The patch was, however, cut out and replaced quite unnecessarily, as the metal was otherwise sound.

An illustration † is also given of a plate from an exploded vulcanising press in which the stay-bolts appeared to have been altered in some manner. Another case ‡ is given to show the grooving and corrosion round stay-bolts in boilers.

**Armour Plates.**—MM. Schneider, in a communication to the *Engineer*,§ defend their own armour plates, and urge that a compound plate has power to break up a projectile of medium quality, because of the extreme hardness of the face. Against such projectiles it acts to the greatest advantage; but projectiles made of chrome steel are more than a match for the hard face, as are also projectiles of large calibre, and once the face is penetrated the backing has no chance. Illustrations of plates are given, and details of various trials, including some made last February at Shoeburyness.

**Ingot Metal for Bridges.**—The following are analyses and mechanical tests of open-hearth metal used in the construction of bridges at Dirschau and Marienburg : ||—

* Vol. x. pp. 97–99.
† *Ibid.*, pp. 66–68.
‡ *Ibid.*, pp. 1-2.
§ Vol. xviii. pp. 27-30.
|| *Stahl und Eisen*, vol. ix. p. 814.

| | Chemical Composition. | | | | | Tensile Strength. | Elastic Limit. | Elongation per Cent. | |
|---|---|---|---|---|---|---|---|---|---|
| | C. | Mn. | Si. | S. | P. | Tons per Sq. Inch. | Tons per Sq. Inch. | On 7·87 Inches. | On 3·94 Inches. |
| Sheets and angles | 0·183 | 0·480 | 0·020 | 0·034 | 0·055 | 25·4–28·6 | 14·6–17·1 | 23–33 | 27–40 |
| Bearing parts, Cast | 0·350 | 0·600 | 0·250 | 0·430 | 0·075 | 28·6–34·9 | ... | 9–24 | – |
| Bearing parts, Forged | | | | | | 38·7–45·7 | | 10–22 | |

**Malleable Iron and Steel Eye-Bars.**—Mr. C. Gayler, in a paper recently read before the St. Louis Engineers, United States, pointed out that steel is very rapidly replacing iron in the manufacture of eye-bars. Very small percentages of phosphorus, however, appear to render steel useless for the purpose, and bridge companies have found it necessary to limit the possible percentage to 0·04; the percentage of carbon should be from 0·1 to 0·2. The steel used for eye-bars in the construction of the Grand Avenue Viaduct, St. Louis, is Bessemer metal containing from 0·13 to 0·16 per cent. of carbon, and from 0·03 to 0·06 per cent. of phosphorus. The tensile strength of this metal was from 62,000 to 70,000 lbs. per square inch, with an elastic limit of 32,000 lbs. The minimum elongation was 18 per cent., and the ¾-inch bar had to bend 180° around its own diameter without cracking. In the manufacture of the eyes, the excess of material across the eye over the bar was 40 per cent.

**Chain Cable.**—M. Meurgey * has published a report by M. de Saint-Hilaire on a new form of chain cable invented by M. Delage. The cable consists of a number of wire helices threaded into each other corkscrew fashion with a screw bolt passed between each pair of helices at their intersection. The bolt heads and nuts lie alternately on opposite sides of the cable, and the ends of the helices are secured to the bolts. Each helix is somewhat flattened to give an oval section, and each turn in the helix bears on the bolt at both ends and takes up its share of the strain.

A chain with seventeen turns in each helix, made of wire Nos. 20, 21, or 22 (French), has a thickness of 9·84 inches, with 52 helices to the yard. Taking the tensile strength of the wire as 38 tons per square inch, chains made of the above sections of wire will support 55,000, 70.000, and 88,000 lbs. respectively. Some results of tests given

* *Rendus Mensuels de la Société de l'Industrie Minérale*, 1889, pp. 70–79.

later by M. Buisson * show, however, that the breaking strain is only 48,280, 59,083, and 66,799 lbs. respectively, a result much inferior weight for weight to that of wire and other ropes.

The report then deals with the adaptability of this form of chain for coal-mining purposes. Ropes of vegetable fibres are stiff and heavy, wire ropes are also very stiff. Chains will wind round a small drum, but are clumsy, likely to break in a badly welded link, and liable to crystallisation. The form of chain under consideration, however, will bend as easily as an ordinary chain, and at the same time each link is composed of several turns, so that it can yield somewhat, and one turn may even be broken without the whole link giving way. Besides this the chain is not liable to crystallisation, may easily be examined, and may be made of any quality of wire.

The weight of the chain is its most serious objection, but this might be reduced by flattening the helices still more, by using hollow bolts, and by using a thinner wire.

* *Comptes Rendus Mensuels de la Société de l'Industrie Minérale*, 1889, p. 92.

# PHYSICAL PROPERTIES.

**Hysteresis in the Relation of Strain to Stress.**—When iron wire is subjected to the alternate application and removal of stress certain of its qualities exhibit hysteresis or lagging in responding to the charge of stress. This lag varies from point to point in a cycle, as is shown by Prof. J. A. Ewing.* Similar changes have been shown to exist in the magnetic and thermo-electric properties. Experiments were made by loading and unloading a long wire, and observing the facility with which the elongation followed the load. In the most successful form of apparatus a long wire was suspended in a flue to keep it as nearly as possible at a constant temperature. Two other wires were suspended near by to form a fulcrum for a mirror attached to the first wire in order to remove as far as possible all effects of temperature. Readings could be taken to show an extension of 0·000,000,102 of the length of the wire.

The wire was kept stretched by a constant weight, and a load of 20 kilogrammes was put on and taken off several times at varying rates. When the operation was performed as quickly as possible the difference of extension between the point at which 10 kilogrammes had been put on, and the point at which 10 kilogrammes had been taken off, amounted to 0·00,000,357 of the length of the wire, equal to a difference of 66 grammes in the load. The hysteresis appeared to be permanent under some conditions, as an interval of two hours did not affect it, but it varied according to the rate of loading. The trial mentioned above was made with hard drawn iron wire, 1·08 millimetre diameter; other experiments were made with mild and hard steel wires.

The experiments show that under certain conditions there is a departure from Hooke's law, one effect of which is that work is done on the material when it is put through a cycle of stress change. The results obviously bear on the conclusions of Wöhler with regard to the deteriorating effect of repeated variations of stress.

* Paper read before the British Association Newcastle meeting).

**Magnetic Viscosity.**—Professor J. Ewing * has tested the question of the apparent magnetic viscosity of iron, and finds that the iron will not take its full magnetisation directly the current is applied. That the effect is not due to Foucalt currents is shown by using a bundle of iron wires instead of a bar. It is improbable that these currents would be sustained long enough to account for the viscosity.

**The Brittleness of Iron.**—A. Ledebur † publishes an account of a further series of experiments on the influence of dipping in acids on iron. In his previous experiments the author not only showed that the hydrogen produced by such treatment on the surface of the metal renders it brittle, but also that the action of moist air produces the same effect. These experiments seemed, however, to show that the tensile strength and the power of being drawn into wire were not seriously affected, and that it was the bending capacity alone which was greatly diminished. To prove these points definitely a further and more extended series of experiments was instituted. A large number of experimental results are given, and in his general conclusions the author states that the results previously arrived at have been confirmed, the tensile strength of neither iron nor steel being diminished by the hydrogen evolved when the metal is dipped in acid, whilst the bending capacity becomes less. The resistance to pressure was found to be diminished but to a very slight extent. The chemical composition of the metal treated was found to very greatly affect the results of the experiments. Bädecker has shown that the presence of combined carbon increases the action of the acid, and these experiments show that the presence of much silicon diminishes such action. The influence in this direction of phosphorus and manganese was not determined. The greater the diameter of the piece of metal attacked, and the less the duration of contact, the less deleterious is the result. When it is a question in dipping metals in acids of avoiding brittleness, a very weak acid must be used, and the metal must not be allowed to remain for any length of time in contact with it. When metal has been rendered brittle by this treatment it will recover its original character if it is allowed to remain for some time in a dry place, or in a much shorter time if it is heated slightly.

Rusting affects iron and steel in a similar manner to acid dipping, but in a very much slighter degree. Although contact with zinc

* Paper read before the British Association; *Industries*, vol. vii. pp. 311–312.

† *Stahl und Eisen*, vol. ix. pp. 745–755.

renders the iron more susceptible to brittleness when in acid solution, yet this is only occasionally the case when iron materials coated with zinc are affected by rust. Coating with zinc appears to increase the brittleness of iron, but this may possibly be due to the preliminary acid dipping process to which the iron is in such cases submitted.

**Physical Properties of Steel at High Temperatures.**—Mr. J. E. Howard gives the results of careful experiments made at the Watertown Arsenal. In the tests the temperature was calculated from the co-efficient of expansion. The tensile strength of steel diminishes from 0° F. to a minimum between 200° F. and 400° F., milder steels reaching the minimum at a lower temperature than hard steels. From this point the tenacity increases to a point between 400° to 650° F. The greatest loss, between 70° and 295° F., was 6·5 per cent., and the greatest gain over the strength at 70° F. was 25·8 per cent. at 460° F. The elastic limit appeared to diminish with increase of temperature, and is well defined at moderate temperatures. The reduction of area in mild steels is somewhat less at 400° to 600° than at atmospheric temperatures, while hard steels show substantially the same contraction up to this point. Above 500° to 600° F. the contraction increases with the temperature. One specimen, fractured at 1572° F., contracted 98·9 per cent. Riveted joints and steel boiler-plates were also tested, and in some cases showed greater strength at 300° F.

**Surface Tints on Iron and Steel.**—S. Stein * has proved that the colours which form on iron or steel when the metal is slowly heated in air are really, as was supposed, due to surface oxidation. He points out that similar colours form on pig iron, and that this is more especially the case with high carbon speigeleisen.

L. Loewenherz † discusses the mode of formation of the surface tints produced in the tempering of steel. The author has employed an air bath for this purpose, and shows by illustrations the arrangement adopted. The requirements necessary for the formation of the several tints are considered, and it is pointed out that the order of the appearance of the colours usually found in text-books is inaccurate, especially as regards the order "purple," "dark blue," "light blue," &c. The results of a number of experiments relating to the formation of the

* Paper read at the June Meeting, 1889, of the Niederrheinische Gesellschaft für Natur- und Heilkunde.

† *Zeitschrift für Instrumentenkunde*, vol. ix. pp. 316–337.

various colours are given in tabular form, and the author shows that the degree to which the steel must be heated to produce any given colour is in direct ratio to the hardness of the steel; and further, that the chemical composition of the metal affects the formation of the several tints to a still higher degree than does a variation in the degree of hardness. The shape, too, of the metal is not without importance.

It is generally assumed that the colours and temperatures obtained in tempering steel correspond with each other, and with the particular temper of the metal. This subject has been investigated by Mr. T. Turner,* and it is shown that these factors do not correspond, as usually believed. The range of temperature used in tempering extends only from about 220° to 320° C. The correct temperature between these points is taken from the colour, or is adjusted by a thermometrical device or by a bath.

The different colours are the result of a film of oxide of variable thickness. From this it appears self-evident that the colours will depend on local conditions, such as the conditions of the surface as regards roughness, dirt, &c., and on the time during which the sample is heated. That this is so is shown by the author. Strips of steel were heated in an air bath while lying on a copper plate to secure uniformity as far as possible. A rough surface of steel gives about the same shade of colour as a smooth surface, but the brilliancy is not so great. Some kinds of dirt retard oxidation, others assist it. The chemical composition does not appear to have great effect, for wrought iron is coloured similarly to steel.

Time appears to be the most important factor in the production of colours. Any colour may be produced by heating for a sufficient time at a much lower temperature than that appropriated to the colour in question. Thus straw colour can be produced in a few minutes at fully 50° under 221° C., which is its generally accepted temperature. It will be found that the time required to pass from shade to shade up the series is longer for any particular colour than for the one before it. Thus, at a given temperature to pass from light straw to straw requires only a few minutes, but it may need as many hours for the change from purple to blue. In this way a purple can be produced in a few minutes at 250° C., in an hour at 220° C., and in twelve hours at 170° C.

Tests made to determine the intervals of change at one definite temperature seem to show that the thickness of the film, and accord-

* *Proceedings of the Birmingham Philosophical Society*, vol. vi., part 2; *The Chemical News*, vol. lx. pp. 190–193.

ingly its colour, requires intervals, lying on a logarithmic curve, for its development. At 150° to 160° C. the colours can successfully be produced, and probably also at still lower points. Besides, the change of colours produced by the time of heating the temper may also change, but the author has not yet obtained quantitative results in this direction.

**The Micro-Structure of Iron.**—In a paper read before the Mining Association for Styria and Carinthia, Professor F. Kupelwieser * discusses the micro-structure and micro-photography of iron. The author points out that practically infinitesimal variations in the chemical composition of the metal lead to great variations in the physical properties. It is possible that these variations may be due to various causes, such as a different arrangement of the molecules of the several substances; the presence of gases not detected by the ordinary method of analysing, these gases being, perhaps, in one instance simply dissolved, and in another actually alloyed with one or other of the various substances present; the variation in temperature, or mode of treatment of the metal. All these, the author observes, are questions to which our present knowledge does not permit an answer to be given.

In studying a fracture by the aid of the microscope it will be found that the difficulties of examination are in proportion to the size of the grain of the metal and the toughness of the material. The author draws attention to the way in which the microscope should be used to avoid such difficulties, and describes the method by which the microscopic section should be prepared. The apparatus employed by the author is similar to that in use by Professor Wedding at the laboratory of the School of Mines at Berlin.

**Defects of Malleable Iron.**—Mr. B. D. Elbers † explains the effects of impurities on iron by the difference in physical properties of iron and the intermixed substances. An impurity that is individually less tenacious or elastic than iron tends to render it cold-short, and if this dissimilarity of behaviour continues or increases in heating, also blue-short and red-short. If the impurity melts or becomes very soft, the pernicious effect is greatly increased, for it acts almost like a blow-hole or blister. These effects, however, diminish as the iron loses its own rigidity. By these means some apparent inconsistencies may be explained in the behaviour of copper, of sulphur, and of other impurities.

* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xxxviii. pp. 299-301.

† *The Engineering and Mining Journal*, vol. xlviii. p. 31.

The probably irregular expansion of iron at different temperatures may set up internal strains and so partly explain the ill effect of numerous reheatings, and further explanation may be sought for in the partial dissociation of the chemical compounds in the iron, combined with the reasoning above.

**Testing Wire Ropes.**—P. Arnould * describes the method of testing wire ropes and the machinery used for the purpose. To hold the ends firmly, a gripping die made in two halves with a conical hole is used. The end of the cable is unreeved for about 4 inches; the individual wires are doubled back into the centre of the rope which is placed in the die. An alloy of equal parts of tin and lead is then poured into the die to surround the folded wires and thoroughly secure the cable.

On the first application of tension the cable straightens and then the strands close together. On the curve of stresses this is shown as a gradual rise, which approximates to a straight line as the real stretching of the metal begins. This straight part should be produced backwards to intersect the base line in order to find the useful stretching of the cable. The straight portion then curves away to the point of rupture.

Illustrations are given of the machine. The test piece is vertical, and attached to the stirrups carrying the dies are rods on which vernier scales are marked. The load is applied by levers, and is marked for each elongation of a millimetre to give data for the curve.

**The Strength of Bessemer Steel Tires.**—Mr. J. O. Arnold † contends that greater durability in steel tires obtained by increased hardness and tensile strength of the steel leads to a corresponding decrease of safety. The question is one affecting the safety of thousands of lives. There is a growing tendency amongst engineers to specify for tires a steel possessing a high resistance to tension. This tends to economy in wear, but it is a question whether such material is not more liable to sudden fracture than more ductile, if less durable, steel. The chemical composition necessary to obtain high tensile strength, together with high elongation, is such as to render steel liable to molecular changes, which produce disastrous results. Working out these conclusions, Mr. Arnold observed that in addition to the iron, the chemical composition of normal tire steel was approximately—Carbon, 0·28 per cent.; silicon, 0·07; manganese, 1·25; sulphur, 0·08; and

* *Le Génie Civil*, vol. xv. pp 362–365, with plate.

† *Minutes of Proceedings of the Institution of Civil Engineers*, vol. xcv. pp. 115–166.

phosphorus, 0·08. A test piece, 2 inches long, 0·564 inch in diameter, and 0·25 square inch area, planed out of a tire so composed, showed on an average a maximum tensile strength of 37 tons per square inch, an elongation of 26 per cent., and a reduction of area of 47 per cent., the fracture being grey and granular with silky edges, and the shape convex and concave. A tire of this material, with an inside diameter of 2 feet 8 inches, and a sectional area of 11 inches, showed a deflection of $6\frac{1}{2}$ inches under a weight of 22 cwt., falling 12 feet, and while it was perfectly adapted to fulfil all requirements, it was proved to be little liable to molecular change under sudden, heavy, and repeated shocks. While an increased proportion of carbon would increase the tensile strength, it would render the tire liable to break under the falling weight test. The only means, therefore, of increasing the tensile strength, and at the same time preserving the normal deflection, was to increase the manganese. Similar tests of a steel practically identical in composition with that given above, but with the addition of 0·5 per cent. of manganese, showed that the tensile strength was raised from 37 to 42 tons per square inch; the elongation reduced from 26 to 18 per cent., and the reduction of area decreased from 48 to 26 per cent., while it required $15\frac{1}{2}$ foot-tons additional to produce equal deflection. But a tensile strength of 48 tons, an elongation of 15 per cent., and a deflection of 2 inches to the foot, has been specified, and to obtain this by adding manganese would require 2·5 per cent. of that element. No steel-maker would risk the inevitable brittleness of such a metallurgical deformity. Hence, chromium is resorted to, and this, added in small quantities, raises the tensile strength in a remarkable degree without seriously diminishing ductility, but when added in too high a proportion it induces brittleness. The results of tests made of tire-steel containing 0·42 per cent. of chromium, and 1·54 per cent. of manganese, showed a tensile strength of 49·8 tons per square inch, 15 per cent. elongation, and 26 per cent. reduction of area, the fracture being flat and finely crystalline, and the falling weight showing a deflection of nearly 12 inches at a 20-feet fall. But tests of the broken tire showed that the tensile strength was 47·7 tons per square inch, the elongation 3 per cent., and the reduction of area 6·4 per cent., the fracture exhibiting large crystals. The molecular change set up by the shock and vibration of the falling weight was thus most clearly indicated; and, although it was possible to get a tensile strength of 50 tons per square inch, together with great strength under the drop test, such tires were very uncertain. Further tests showed that the effect of annealing was not

only to raise the ductility of steel, but also to cause a molecular arrangement capable of great resistance to alteration under vibration and shocks. The presence of too much chromium is also found to occasion a loss of ductility, and the amount of work put upon steel is shown to have a marked relation to the molecular structure, and consequently to the ductility of the material.

**The Tensile Strength of Steel Rails.**—Professor Wedding * points out that, in proof of the accuracy of his statement that the tensile strength of rails should be from 29 to 30·5 tons per square inch and should scarcely ever reach 32 tons, of one hundred and forty-seven rails which were submitted for testing to the German Commission for railway material, as examples of rails which had stood well in practice, eighteen or 12·24 per cent. had a tensile strength of less than 32 tons. On the other hand, of seventy-nine rails which had proved of bad quality only six, or 8·69 per cent., had a tensile strength of less than 32 tons to the square inch. Of the former, sixteen showed a sufficient elongation, whilst in the case of the latter series only two reached the required standard. Since the introduction of basic Bessemer steel for rails, the tendency is still more in favour of the author's statement as to the desirability of a low tensile strength, since the relatively high percentage of phosphorus in the acid metal induced the desirability on the part of the manufacturer of a high tensile strength for the rail. In view, too, of the use of heavier rails on the German railways, a tensile strength of 32 tons to the square inch will become impracticable.

**Mechanical Tests of Chrome Steel.**—According to R. Busek,† a specimen of chrome steel manufactured by the Terre-Noire Company had the following partial composition:—

| C. | Si. | Mn.‡ | Cr. | P. | S. |
|---|---|---|---|---|---|
| 0·45 | 0·28 | 0·75 | 0·75 | ... | trace |

This steel, produced as a casting free from blow-holes, gave the following results when submitted to tensile tests without any previous rolling or smithing, the test pieces being bars 3·94 inches in length, and 0·55 inch in diameter:—

| | Elastic Limit. Tons per Square Inch. | Tensile Strength. Tons per Square Inch. |
|---|---|---|
| Unhardened . . . . | 23·05 | 40·00 |
| Hardened in oil . . . . | 24·32 | 55·36 |

* *Stahl und Eisen*, vol. ix. p. 492. † *Ibid.*, vol. ix. p. 728.
‡ Mg in the original.

The elongation of the unhardened bar was 2·2 per cent., and of the hardened bar 10·0 per cent. Calculated on the final reduced area, the tensile strength of the hardened bar was 62·28 tons.

Test cylinders each approximately 0·39 inch in height, and the same in diameter, were then weighted with a load of 32 tons. After having been submitted to this stress, it was found that the unhardened cylinder was reduced in height from 0·39 inch to 0·20 inch, and that of a cylinder hardened in oil from 0·38 inch to 0·23 inch; a similar cylinder which had been hardened in water was reduced in height from 0·41 inch to 0·38 inch.

**Tensile Tests of Hungarian Basic Steel.**—A. Gouvy* gives the following results of tests of basic open-hearth steel made at the Resicza Steel Works, Hungary:—

| No. | Percentage Composition. | | | | Tensile Strength. | Elongation. | Reduction of Area. |
|---|---|---|---|---|---|---|---|
| | C. | Si. | P. | Mn. | Tons per Square Inch. | | |
| | | | | | | Per cent. | Per cent. |
| 1 | 0·220 | 0·025 | 0·014 | 0·350 | 22·03 | 32 | 72·0 |
| 2 | 0·177 | 0·012 | 0·014 | 0·115 | 21·78 | 29 | 68·4 |
| 3 | 0·232 | 0·023 | 0·011 | 0·022 | 22·98 | 25 | 70·8 |
| 4 | 0·191 | 0·035 | 0·011 | 0·151 | 20·00 | 28 | 75·5 |

The results of a number of other tests are also given.

**Drifting Tests.**—Mr. A. C. Cunningham † gives the results of a number of drift tests of steel. In one case a plate was examined which contained 0·073 per cent. of phosphorus, and had a tensile strength of 65,000 lbs. per square inch. The original punched hole was of $\frac{7}{16}$-inch diameter, and the centre of the hole was 1 inch from the rolled edge and 4 inches from the sheared end. After drifting to $1\frac{1}{2}$-inch diameter, an increase of 245 per cent., a hole of the same size as the original one was punched at the side of the drifted hole. Two other tests made with a plate containing 0·006 per cent. of phosphorus, and having a tensile strength of 46,000 lbs. to the square inch, showed still more favourable results.

Successful drifts, the author states, become the more difficult to

* *Stahl und Eisen*, vol. ix. p. 401.

† *The Engineering News*, through *Iron Age*, vol. xliv. p. 43.

make as the hole approaches a sheared edge, especially when sheared across the direction of rolling. In these cases the cracks start at the sheared edge, and not at the hole itself. In a case in which it was desired to ascertain whether a very large quantity of steel plate which had been punched with $1\frac{1}{4}$-inch holes could be safely used without reaming or annealing, the drift test was successfully applied, the holes being enlarged to $2\frac{1}{4}$ inches without crushing the material either at the inside of the holes or on the exterior sheared edge. This, it was considered, showed that annealing and reaming would not be necessary. In order to determine whether other steels would give as good results, similar tests were made with a much harder steel, the tensile strength of which was from 62,000 to 68,000 lbs. per square inch. One-half of the test pieces were reamed after punching, and the other half left as they came from the punch. The tests were also duplicated in iron. The following table gives a summary of the results:—

| | $\frac{3}{8}$-inch Steel Plates. | | $\frac{3}{8}$-inch Iron Plates. | |
|---|---|---|---|---|
| | Holes Punched. | Holes Punched and Reamed. | Holes Punched. | Holes Punched and Reamed. |
| | Per cent. | Per cent. | Per cent. | Per cent. |
| Minimum result . . | 54 | 93 | 54 | 46 |
| Maximum result . . | 123 | 100 | 54 | 46 |
| Average result . . | 97 | 106 | 54 | 46 |
| | $5 \times 3\frac{1}{2} \times \frac{3}{8}$ Steel Angles. | | $5 \times 3\frac{1}{2} \times \frac{3}{8}$ Iron Angles. | |
| Minimum result . . | 92 | 33 | 36 | 24 |
| Maximum result . . | 115 | 176 | 36 | 24 |
| Average result . . | 100 | 73 | 36 | 24 |

In these tests the external edges of the angles and plates were mill-rolled.

Another series of tests was made with holes punched within two diameters of edges that were sheared, the results being as follows:—

| | Steel Plates. | Steel Angles. | Iron Plates. | Iron Angles. |
|---|---|---|---|---|
| | Per cent. | Per cent. | Per cent. | Per cent. |
| Minimum result . . | $11\frac{1}{2}$ | 10·8 | 15 | 14 |
| Maximum result . . | 14 | 12·0 | 17 | 15 |
| Average result . . | 12 | 11·4 | 16 | $14\frac{1}{2}$ |

**Steel for Gun-Barrels.**—Mr. R. W. Hunt * observes that steel for gun-barrels must be low in manganese, as when much is present the steel throws a long chip before the drilling tool. A very satisfactory metal had the following composition:—

| Carbon. | Silicon. | Phosphorus. | Sulphur. | Manganese. |
| --- | --- | --- | --- | --- |
| 0·290 | 0·212 | 0·048 | 0·065 | 0·370 |

Manganese is further deleterious in that it strongly affects the hardening properties of steel, giving rise to the formation of water-cracks.

**An Automatic Testing Machine.**—The *Iron Age* † illustrates the latest form of testing machine constructed by Messrs. Tinius Olsen, of Philadelphia. One end of the test piece is attached to the upper plate of the machine and the other end to the lower plate. The lower plate or cross-head is secured to four straining-screws which pass through holes at the carriers of the weighing platform of the machine, through openings in the levers and bed-plate, and enter the driving-nuts situated below the latter. Feathers fitting into longitudinal slots cut through the threads of the screws prevent them from turning, and they therefore either rise or fall and carry the lower plate with them as the nuts are rotated. These nuts are operated through bevel gearing by outside spur gearing and a counter-shaft. The counter-shaft is provided with double cone and friction pulleys, admitting of six downward or pulling speeds and two upward speeds.

For tensile tests the ends of the specimen are secured to the plates by steel wedges which enter rectangular openings cut through the centres of the plates. Interposed in the space between the wedges proper and the plate are spherical surface bearings by which the wedges are adjusted to the specimen, and the specimen is adjusted centrally and on a parallel line to the line of greatest stress, and a straight pull secured.

The weighing apparatus consists of the main levers upon which the platform rests, three in number, so constructed as to act as a single lever, and supporting the platform upon which rest the columns which carry the upper plate or cross-head. As one end of the specimen is secured in the upper cross-head any stress imparted to the specimen by the lower straining-head will be communicated through the columns and platform to the levers. The stress on the main lever is through an intermediate lever connected to the beam, where the amount is balanced and thus registered. The stresses are automatically balanced on the beam, this being accomplished by a coarse-thread screw placed on the top of the beam, the sliding weight being moved by this screw. At

* *Journal of the Franklin Institute*, vol. cxxvii. p. 375.
† Vol. xliii. p. 956, 2 illustrations.

the end of the screw and also at the extreme end of the beam nearest the machine is secured a wheel by which the screw is operated. A small friction-pinion is fitted into a groove in this wheel. The pinion is continually driven by a belt from the counter-shaft.

In order to make connection between the pinion and the wheel the pinion-shaft bearing is mounted on one end of a lever the other end of which is controlled by an electro-magnet. The circuit is broken and connected by the vibration of the beam. Thus the raising of the beam completes the circuit, when the magnet attracts the lever and throws the friction-pinion in contact with the wheel, and the screw revolves. When the beam drops, the reverse takes place. The wheel at the end of the screw besides operating this also serves as a dial vernier for reading the smaller fractions of the stresses.

The machine is also provided with means by which it graphically records the result of the test. In order to do this the distortion of the specimen under test must not only be observed but transferred to a piece of paper which is mounted on a drum on the beam, in front of which is the pencil for marking the diagram. This pencil is moved axially along the drum by the same screw that moves the poise on the beam, and thus the motion indicates the stress on the specimen. The rotary motion of the drum is reserved to show the distortion of the specimen. On the test piece are secured small heads a certain distance apart, say 6, 8, or 10 inches, the distance in which the distortion, or, in case of tensile tests, the elongation is to be observed. Between the heads are placed small cylinders partly filled with water, a similar cylinder being placed on the beam in front of the drum. These cylinders are then connected through a collector and reservoir by the aid of which the arrangement is controlled and operated. The drum carrying the paper can be connected directly with the cylinder in front of it, and when all is properly adjusted any expansion of the cylinders and their pistons on the specimen, caused by its elongation, will cause a corresponding contraction of the cylinder and piston in front of the drum, and this motion is transferred to the drum on which the line is drawn.

# CHEMICAL PROPERTIES.

**Effect of Manganese on Chill.**—Some recent experiments * have been made on the effect of manganese on chill. Starting with 1 lb. of manganese to the ladle capable of pouring a 550-lb. wheel, the addition was increased at ½ lb. a time. Up to 7½ lbs. there was no appreciable effect, but from this point up to 10 lbs. the depth of chill increased from a trifle over half an inch to three-quarters of an inch. The principal peculiarity noticed throughout was the fibrous extensions of the chill down into the grey iron, whereas the inner edge was straight when no manganese was used.

**The Rusting of Rails in Tunnels.**—Mr. Thörner † has analysed a large number of samples of rust taken from the surfaces of rails laid in tunnels. The author finds that sulphuric acid is always present in considerable quantities, and he shows that the gases escaping from locomotives, besides containing sulphurous anhydride, contain unexpectedly large quantities of sulphuric acid, and that it is to this cause that the undue rate of oxidation of ironwork in railway tunnels is due. The author further finds that those parts of the ironwork which are kept wet by dropping water are less oxidised than other parts which are not subject to this action.

**Bessemer Steel.**—In an address delivered before the Franklin Institute, Philadelphia, Mr. R. W. Hunt gave the following results of analyses of various articles made of Bessemer steel:—

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* *National Locomotive and Car Builder*, through *American Manufacturer*, vol. xlv. No. 7.

† *Stahl und Eisen*, vol. ix. pp. 821-836.

| Steel for | Carbon. | Silicon. | Phosphorus. | Manganese. |
|---|---|---|---|---|
| 1. Planters' hoes . . . . | 0·76 | 0·185 | 0·059 | 0·441 |
| 2. Scarf steel . . . . | 0·52 | 0·150 | 0·068 | 0·406 |
| 3. Circles and plungers for rifles . | 0·66 | 0·171 | 0·057 | 0·416 |
| 4. Machine screws . . . | 0·46 | 0·223 | ... | 0·316 |
| 5. Hoes . . . . . . | 0·61 | 0·158 | 0·086 | 0·445 |
| 6. Pitchforks and large forks . | 0·63 | 0·241 | 0·073 | 0·610 |
| 7. Planters' hoes . . . . | 0·52 | 0·150 | 0·043 | 0·376 |
| 8. Gooseneck hoes . . . | 0·53 | 0·249 | 0·040 | 0·413 |
| 9. Spring steel, Jenks' English . | 0·64 | 0·145 | 0·088 | ... |
| 10. Spring steel, Jenks' English . | 0·52 | 0·150 | 0·060 | 0·030 |
| 11. Spring steel, Graves' Swedish . | 0·53 | 0.110 | 0·030 | ... |
| 12. Spring steel, Graves' Swedish . | 0·76 | 0·840 | 0·018 | 0·085 |
| 13. Spring steel . . . . . | 0·65 | 0·185 | 0·102 | ... |
| 14. Hatchets . . . . . . | 0·70 | 0·270 | 0·041 | 0·195 |
| 15. Swords . . . . . . | 0·64 | 0·258 | 0·017 | 0·453 |
| 16. Scythes (German steel) . . | 0·63 | 0·127 | 0·056 | 0·212 |
| 17. Cutlery, knife . . . . | 0·51 | 0·180 | 0·029 | 0·265 |
| 18. Fork . . . . . . . | 0·49 | 0·335 | 0·030 | 0·444 |
| 19. Cutlery . . . . . . | 0·61 | 0·210 | 0·046 | 0·402 |
| 20. Tool . . . . . . . | 0·88 | 0·220 | 0·023 | 0·140 |
| 21. Tool . . . . . . . | 0·85 | 0·204 | 0·022 | trace |
| 22. Tool . . . . . . . | 0·85 | 0·190 | 0·022 | 0·174 |
| 23. Tool . . . . . . . | 0·86 | 0·216 | 0·030 | 0·001 |

No. 1 and 2, Lane, Gale & Co. ; 3. Providence Tool Company ; 4. Hartford Machine Company ; 5 and 6. Huntly & Babcock, Utica, New York ; 7 and 8. Remington ; 13. Naylor's, Bridgeport, Connecticut ; 14. Johnsville Axle Works ; 15. Ames & Co. ; 16. Stock used by A. S. Millard ; 17 and 18. Landers, Frary & Clark, New Britain, Connecticut ; 19, 20, 21, and 23 made by Park Brothers ; 22. Frith's English.

**Thermo-Chemistry.**—In discussing the paper read by Mr. A. Pourcel before the Iron and Steel Institute, Professor Ledebur * points out the great importance of the question of thermo-chemistry. Before, however, any accurate calculation can be made, it will be necessary to determine definitely in what state of combination the various substances exist which occur in a bath of molten iron, and what are the real products of the combustion of such impurities. Now, neither the one nor the other of these points is in any way settled. Further, the influence of mass and temperature in determining the reactions must not be overlooked.

* *Stahl und Eisen*, vol. ix. pp. 712-717.

# CHEMICAL ANALYSIS.

## CONTENTS.



## I.—*ANALYSIS OF IRON AND STEEL.*

**Sampling of Materials Used and Produced in the Manufacture of Iron and Steel.**—The proper sampling of materials is a matter of great importance, for on it depends the value of an ore, of a mining property, the correctness of the charges for the blast furnace, and much else besides. Some rules for proper sampling are given by Mr. G. L. Luetcher.*

*Ore.*—The sample of ore from cargoes, trucks, or mines should represent both the dry and the wet condition with all impurities. Moisture can best be determined from a sample taken from holes in the ore 2 feet deep, or after it is tipped in the case of mined ore. Everything should be taken as it comes, and about 200 lbs. dried in a shallow iron box over the boilers for about ten hours. Up to a ton may be taken if the ore can be worked up in a grinding pan, and of this about 200 lbs. should be taken as representative.

*Ore in Mines.*—Each heading should be sampled and analysed separately, or else a proper proportion should be taken from each heading or working place. A heading may be sampled by dividing the face into square feet and taking an equal amount from the centre of each square. If the vein or seam lies in uniform strips, then a transverse section should be taken. Ores of different character should be sampled separately. In sampling the "run of the mine," equal quantities of coarse and fine should be taken from each car.

* *American Manufacturer*, vol. xlv. No. 8.

*Ores in Trucks and Piles.*—Soft ores are generally well mixed and moist, so that from a shovelful to a handful may be taken from the bottom of six to twelve holes 2 feet deep in every truck. To this must be added a few pieces from the lumps which generally lie on the outside. Hard ores are best sampled by laying a knotted string diagonally across the trucks; the knots are 18 inches apart, and a piece is broken off each lump which lies under a knot. Piles should properly be sampled by several cuts right through; but this is generally too expensive, so holes about 2 or 3 feet deep may be dug in as many places as possible, in the proportion of three at the top, five in the middle, and seven at the bottom and both sides. Out of these holes equal amounts from a handful to a shovelful should be taken, and some pieces added from the large lumps at the bottom.

*Working up the Sample.*—No matter how obtained, the 200-lb. sample after drying should be broken to a size that will pass a sieve with two meshes to the inch. It is sifted twice to mix it well, and then poured by shovelsful exactly on to the centre so as to form a uniform pyramid, of which a quarter section is taken. This is reduced to pass through a sieve with four meshes to the inch, and the above process is repeated. Again the operations are repeated with an eight and a twelve sieve to reduce the final sample to about a pound. The utmost cleanliness must be observed during these operations.

*Coal, Coke, and Limestone.*—These may be sampled in a similar manner. Coal is best taken by a vertical slice of the seam, and should be broken up by the hammer to avoid dust. Coke and limestone may be ground. The fine and dirt-like parts must not be neglected.

*Pig Iron.*—Scotch pig, No. 1 to mottled, may be drilled. Sand, oil, and water must carefully be avoided. The start is made with a large drill to get a clean surface, and borings are then taken all through with a ½-inch drill. Pigs should not be drilled in the centre of a breaking surface, but right through from the flat to the round side. The coarse and fine parts may be mixed with alcohol, and ground to get a uniform sample. If the sample has to represent a cast, small spoonsful of metal are taken at equal intervals from the runner and poured into a small ingot mould 3 by 4 by 6 inches. This sample will cool quickly, so that a fracture may be obtained, and it should be drilled through in a direction perpendicular to the layers of metal. If the sample of the cast is taken from the pigs, a piece is taken from a pig at the bottom and from one at the top, and two at one-third and two-thirds from the bottom. After a slip in the furnace, samples must

be taken from each bed. If the metal be poured into water to obtain shot, the phosphorus and sulphur are affected.

Truck loads and piles should be sampled both at the top and bottom; six to twelve pieces may be considered to represent a truck. White iron, spiegeleisen, and ferro-manganese are sampled by breaking specimens, about hazel-nut size, from several pieces, and pounding these in a mortar until all passes a No. 20 to 40 sieve. Care must again be taken to remove sand, and to keep the coarse and fine well mixed.

*Steel and Wrought Iron.*—If taken from a melt, the bath should be well stirred, and the sample should not be cooled in water. A finished heat is sampled by taking a 2-lb. ingot between the two middle ingots. The test ingot may be cast in an iron mould, of which the lower end may be set in water after casting to cool it more quickly. Drillings from large ingots are not satisfactory, as large variations occur in the different parts. Blooms and muck bars should be drilled in fine drillings from the hammered surface as deep as possible, and slag particles kept well mixed with the drillings. Chrome and other hard steels are sampled by pouring on a cold iron plate, when small shot are obtained. Large castings of this nature may be chipped.

*Slag.*—Blast furnace and other slags should be sampled before they come in contact with water, coke, or sand. Sampling by inserting a cold rod is not advisable. A clean sample should be taken in a small cast iron mould from each flush between two casts, or during twenty-four hours. Before analysis, metallic iron should be removed by a magnet. To determine the total iron in the slag, a 200-lb. sample is weighed, crushed, and the larger lumps of metal are picked out by hand. The mass is then quartered, &c., as usual, and the total iron is determined by calculations based on the weight of the sample, the metallic iron separated, and the percentage of combined iron.

*Gases.*—Gases are sampled above water, which must first be saturated with the gas. Moisture is determined by a calcium chloride tube. If used for immediate analysis, the gas may be collected in a bottle, from which the water is run into a second bottle placed below, but if the sample is to be preserved, it should be drawn off into rubber bags. A convenient method of filling them is to place them in a strong iron vessel filled with water. The water is run off, and the bag dilates accordingly. Gas ought to be sampled during several charges from a blast furnace and from a producer, while the fire is being stirred, when new coal is put in, and while neither of these is taking place. Pressures and temperatures should both be noted.

All samples should be carefully packed in water-tight vessels and plainly marked. The accompanying note should contain the corresponding description, and full particulars of the circumstances under which the sample was taken.

**Determination of Carbon in Iron.**—L. Blum * controverts the statement made by L. L. de Koninck † that the addition of silver sulphate prevents the evolution of chlorine in the Ullgren chromic combustion process, and shows by experiment that silver chloride, when heated with the usual mixture of chromic and sulphuric acids, is decomposed with evolution of gas.

In the modified form of apparatus for the determination of carbon by the Wiborgh method, introduced by Dr. M. A. von Reis, ‡ the steel is dissolved in a flask having a capacity of 200 cubic centimetres. The neck of the flask is about 6 centimetres in length, and has an internal diameter of 22 millimetres. It is closed by a two-holed stopper. Through one of these perforations a funnel-tube, provided with a glass tap, is inserted, whilst through the other opening a 5-millimetre glass tube is passed. This tube is coiled on itself, and is surrounded with water in a glass condensing vessel. The apparatus employed to measure the carbonic anhydride consists of a graduated measuring tube surrounded by a wider tube filled with water, the temperature of which is shown by a thermometer attached to the inner measuring tube, and of an absorbing potash-tube partially filled with fine-drawn glass rods. The operation is performed in the manner described by Wiborgh, except that much larger quantities of metal are taken for the test. Thus, when the carbon is less than 0·5 per cent., 3 grammes are weighed out; with carbon from 0·5 to 1 per cent., 2 grammes; from 1 to 2 per cent., 1 gramme; 2 to 4 per cent., 0·5 gramme; and when a still higher percentage of carbon is present, 0·3 gramme. For each gramme of metal 10 cubic centimetres of a saturated neutral solution of copper sulphate is added, and allowed to act on the iron for from one-half to one hour, shaking frequently; then for every gramme of iron 5 cubic centimetres of a solution of 1 gramme of chromic anhydride in 1 cubic centimetre of water is added. Next there is added carefully 120 cubic centimetres of sulphuric acid of 1·65 specific gravity (100 parts con-

* *Zeitschrift für Analytische Chemie*, vol. xxviii. pp. 450–452.

† *Journal of the Iron and Steel Institute*, 1889, No. 1, p. 393.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xxxvii. p. 295; see also *Journal of the Iron and Steel Institute*, 1888, No. 1, p. 376.

centrated acid mixed with 52 parts water) saturated with chromic acid, and 30 cubic centimetres of weaker sulphuric acid (1·10 specific gravity). The dissolving flask is then full, nearly up to the neck. The solution is then heated nearly to the boiling temperature, and the flame is removed until the first stage of the reaction has partially ceased, after which the solution is again heated and kept at a steady boil. By carefully lowering the pressure-flask connected with the measuring-tube, the carbonic anhydride may be readily collected. Hints are given as to the best method of conducting the operation, and the results of a number of comparative determinations are given to show the accuracy of the process.

**Determination of Phosphorus.**—Mr. T. R. Woodbridge* describes the method used for determining phosphorus in ore from Mineville, New York. The phosphorus is chiefly present as apatite, and is consequently soluble in dilute nitric acid. From ½ to 10 grammes of ore is boiled with 50 cubic centimetres of water and 10 of strong nitric acid for half an hour. The solution is filtered, 15 cubic centimetres each of ammonia and nitric acid is added, and the solution is cooled to 45° C., when 15 to 45 centimetres of molybdic solution is added and stirred vigorously. The yellow precipitate is all down in five minutes; it is dried at 110° C., and 1·63 per cent. calculated as phosphorus. The method is found by the author to give accurate results with these ores, and generally also with magnetites. Dr. D. H. Browne, however, states that the phosphorus is not entirely extracted from hæmatites under an hour's boiling.

Mr. P. W. Shimer * describes the following method:—Dissolve 1 gramme of iron in 29 cubic centimetres of nitric acid of specific gravity 1·20, add slowly 10 centimetres of a 2 per cent. solution of potassium permanganate to the boiling solution, and then 5 cubic centimetres of hydrochloric acid, specific gravity 1·12. Next add 5 cubic centimetres of strong sulphuric acid, and 5 of water. Evaporate till fumes begin to come off. Cool, add 5 cubic centimetres of nitric acid, and enough water to dissolve the residue. Filter and determine silicon in the insoluble residue. Heat the filtrate to 80° C., and add 50 cubic centimetres of molybdic solution. Heat to 60° C. till clear, which takes about an hour, then filter and determine the phosphorus in the precipitate by magnesia mixture. Very exact results are obtained by

* *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 750-754.
† *Ibid.*, pp. 100-103.

this method, and the presence of sulphuric acid does not affect the determinations.

**Influence of Silicon on the Determination of Phosphorus in Iron.**—The usual process for the determination of phosphorus in iron is that proposed by Mr. Emmerton, in which the nitric acid solution is evaporated to dryness, taken up with hydrochloric acid, which is in turn driven off by nitric acid, and the phosphorus precipitated by the molybdic solution. Professor T. M. Drown * has made experiments to see whether it is necessary to separate the silica. The complete oxidation of carbon is absolutely essential, or else, in all probability, the iron is not completely oxidised, but this may be attained by the use of chromic acid, potassium chlorate or permanganate, hydrogen peroxide, or other reagents.

If the nitric acid is strong, complete solution of the silica is not effected, and the solution cannot easily be filtered owing to the gelatinous form of the silica. The percentage of silicon left in the graphitic residue of a No. 1 foundry iron containing 2·42 per cent. of silicon after solution in nitric acid of various strength is as follows :—

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Acid, specific gravity . . | 1·4 | 1·2 | 1·16 | 1·135 | 1·116 | 1·102 | 1·082 | 1·070 |
| Silicon, per cent., average | 2·19 | 6·10 | 0·07 | 0·06 | 0·10 | 0·12 | 0·23 | 0·26 |

The solution in nitric acid filters most readily when the strength of acid is about 1·135 specific gravity, but the varying behaviour of the silica suggests that silicon exists under several conditions in iron. Iron in this solution is preferably peroxidised by potassium permanganate, and the separated manganese peroxide is redissolved by the addition of an organic compound such as tartaric acid. The following is the distribution of silicon in tests made on the above-mentioned iron :—

| Silicon Determined. | Per cent. | Per cent. | Per cent. | Per cent. |
|---|---|---|---|---|
| In residue from nitric acid solution | 0·040 | 0·040 | 0·070 | 0·100 |
| In yellow precipitate . . . . . | 0·030 | 0·050 | 0·012 | 0·012 |
| In washings of the yellow precipitate with 2 per cent. nitric acid . . | 0·050 | 0·030 | 0·007 | 0·004 |
| In filtrate from the yellow precipitate | 2·250 | 2·210 | 2·340 | 2·280 |
| Totals . . . . . . | 2·370 | 2·330 | 2·429 | 2·396 |

* *Transactions of the American Institute of Mining Engineers*, vol. xviii. (Advance proof).

There seems to be no evidence of the formation of any precipitate of ammonium silico-molybdate. If the separation of silica is omitted, much time is saved by using the process adopted in the laboratory of the Massachusetts Institute of Technology. About 1·5 gramme of pig iron is dissolved in 60 cubic centimetres of nitric acid of 1·135 specific gravity by heating on an iron plate. The solution is effected in about three minutes, and is filtered from the graphite ; to the boiling filtrate there is added 15 cubic centimetres of permanganate solution containing 5 grammes of salt to the litre. Boiling is continued till the pink colour has disappeared, and a small quantity of tartaric acid is added to dissolve the manganese oxide. As much as 1 gramme of tartaric acid will not affect the result, but about 0·1 gramme only is required. To the solution 10 cubic centimetres of strong ammonia is added, and it is then cooled to about 90° C. before the addition of 80 cubic centimetres of molybdate solution. From this point the method of reduction by zinc and titration by permanganate is followed.

By the old method, a sample of pig iron containing 2·42 per cent. of silicon gave 0·284 per cent. of phosphorus, and by the new method it gave from 0·272 to 0·294, or by averaging twenty-two experiments 0·285 per cent. In order to attain still greater rapidity the graphite need not be filtered off. Determinations in this manner gave the following results :—

| | Silicon. | Phosphorus. | |
|---|---|---|---|
| | | By the Old Method. | By the New Method without Filtering from Graphite. |
| | Per cent. | Per cent. | Per cent. |
| Grey forge iron . . | 0·63 | 0·632–0·635 | 0·620–0·645 |
| Bessemer iron . . | 1·18 | 0·084–0·087 | 0·083–0·086 |
| Foundry pig iron . . | 2·29 | 0·334–0·330 | 0·322–0·334 |
| Bessemer steel . . | ... | 0·061 | 0·060–0·064 |

**Determination of Silicon.**—For determining silicon in steel, Mr. C. Jones * uses Dr. B. Drown's method with rapid evaporation. The solution is placed in a platinum dish heated by two flames, one below, and the other directed on to the surface of the liquid. It is found that 50 cubic centimetres of nitro-sulphuric acid is evaporated in three minutes, and the salts are left as a thick pasty mass which can be at once

* *Journal of Analytical Chemistry*, vol. iii. p. 121.

dissolved. The results are somewhat high owing to the formation of insoluble ferric oxide, but the time required for the determination is only twenty to fifteen minutes.

For the estimation of silicon in ferro-silicons and silicon spiegeleisens, M. Clerc* prefers the following method :—To 1 gramme of the metal add 15 to 20 cubic centimetres of water, 8 to 10 cubic centimetres of bromine, and then about 75 cubic centimetres of aqua regia. Heat on a sand bath and evaporate down to 50 cubic centimetres. The bromine oxidises the silicon, and the acids attack the iron and manganese. Then add 200 to 300 cubic centimetres of boiling water and filter immediately. Ignite the residue, which will be perfectly pure silica. The time required is four hours, and the residue can be used for the determination of the manganese. The error is about 0·001 to 0·002 per cent., a negligable quantity with alloys containing 10 to 12 per cent. of silicon.

The alloy may also be treated with aqua regia, and afterwards be heated with sulphuric acid till white vapours appear. This method gives good results, but as a rule alloys containing much silicon are difficult to dissolve perfectly by ordinary methods.

**Determination of Sulphur in Iron.**—Dr. M. A. von Reis † discusses the loss of sulphur occurring when iron is dissolved in nitric acid. A portion, he states, escapes in the form of sulphuretted hydrogen. When iron or steel containing sulphur is dissolved in cold nitric acid, the clock glass covering the beaker, in which the solution is effected, becomes covered with a white deposit of sulphur. This occurred even when the acid had been first heated to 60° C.

**Determination of Chromium.**—Dr. Kosmann ‡ proposes a modification of the method of volumetrically determining chromium in iron and steel given by E. Wahlberg.§ The alteration relates to the oxidation of the chromic oxide to chromic acid, as the melting with an oxidising mixture is liable to give rise to loss. The suggested mode of procedure is as follows :—The nitric acid solution of the chrome steel filings is evaporated, with addition of sulphuric acid, until the nitric acid is driven off, but not to dryness. The cooled mass is then taken up with water, with the addition of some hydrochloric acid,

* *Société de l'Industrie Minérale, Comptes Rendus Mensuels*, 1889, pp. 107–109.

† *Stahl und Eisen*, vol. ix. p. 497.

‡ *Berg- und Hüttenmännische Zeitung*, vol. xlviii. p. 204.

§ *Journal of the Iron and Steel Institute*, 1889, No. 1, p. 398.

diluted, and neutralised with ammonia. Then 15 to 20 cubic centimetres of a 10 per cent. solution of hydrogen peroxide is added; an excess of ammonia follows, and the whole is boiled. In this way all the ferric oxide and manganese is precipitated, and the chromic acid is in solution. The liquid and precipitate are then brought to a given volume (500 cubic centimetres), and an aliquot part is filtered into a graduated vessel, from which are taken the quantities to be titrated. These are rendered acid, with sulphuric acid, and titrated with ferrous sulphate and potassium permanganate in the manner described by E. Wahlberg.

C. Reinhardt * describes a method for the determination of chromium in iron and steel, which is based on the fact that chromic oxide is entirely precipitated from solution by zinc oxide whilst ferrous chloride and manganous chloride remain in solution. The reduction of the ferric chloride is effected by sodium hypophosphite. The method is as follows :—Place in a ½-litre beaker 10 grammes of the iron filings to be analysed, and cover them with 100 cubic centimetres of hydrochloric acid of 1·19 specific gravity. When the solution is complete, cool slightly, and add a small quantity of potassium chlorate, heat until the reaction ceases to be violent, and evaporate down to about 50 cubic centimetres. Dilute and filter into a ¾-litre Erlenmeyer flask, and wash the residue with hydrochloric acid diluted with four times its volume of water. The filtrate is then heated to boiling without being diluted, and some 10 or 20 cubic centimetres of sodium hypophosphite solution is added little by little. The heating is continued until the solution has either become colourless, or, when much chromium is present, of a pure green colour, but not yellow. Zinc oxide in suspension in water (zinc oxide milk) is then stirred into the hot solution in excess, the solution is heated for a while, allowed to cool, and filtered. The precipitate is dissolved direct in hot dilute hydrochloric acid, and the filtrate re-treated with sodium hypophosphite and zinc oxide. The precipitate is then filtered as before, carefully washed, dissolved in hot dilute hydrochloric acid, and precipitated with ammonia. Chromium hydrate is precipitated, the zinc remaining in solution. It is desirable to redissolve the precipitate and re-precipitate with ammonia to insure the complete separation of the zinc, then ignite the precipitate in a large platinum crucible, and mix it with 8 grammes of a mixture of four parts common salt, one part sodium carbonate, and one part potassium chlorate. Heat first gently,

* *Stahl und Eisen*, vol. ix. p. 404.

and then more strongly until the fusion is steady; then cool and dissolve, adding a little alcohol to reduce any manganate or permanganate present. Filter the solution, acidulate the filtrate with hydrochloric acid, boil, and evaporate after adding some sodium disulphite. Take up with hydrochloric acid and water, filter off the silica, heat the filtrate in a platinum or porcelain dish on a water-bath, precipitate with ammonia, heat for some time, filter, dry, ignite and weigh as chromium oxide.

**Determination of Copper in Iron.**—C. Reinhardt * dissolves 10 grammes of iron or steel in 100 cubic centimetres of hydrochloric acid and a little potassium chlorate, evaporates to 50 cubic centimetres, and filters. The filtrate is reduced with sodium hypophosphite, as in the case of the chromium determination, allowed to cool somewhat, and the copper precipitated with sulphuretted hydrogen. The author observes that when basic pig iron is dissolved in sulphuric acid diluted with three times its volume of water, none of the copper present in the metal passes into solution.

**Determination of Arsenic in Iron.**—Dr. M. A. von Reis † describes the various methods which have been proposed for the determination of arsenic in iron and steel. He suggests the use of the following:—Dissolve from 10 to 50 grammes of the metal to be examined, according to the percentage of arsenic present, in dilute sulphuric acid. For 10 grammes of metal, a mixture of 100 cubic centimetres of water and 20 cubic centimetres of concentrated sulphuric acid is sufficient. If pig iron is the metal under examination a 750 cubic centimetre beaker must be used for the solution as the reaction is very violent, whilst one of half the size will suffice if steel is being examined. When the main reaction is over the solution is heated and, in the case of pig iron, boiled for ten minutes. It is then filtered rapidly, and washed with hot water. The residue and the filter-paper are then returned to the beaker. In the case of ingot iron 20 cubic centimetres of a 2 per cent. solution of permanganate and 20 cubic centimetres of hydrochloric acid are charged into the beaker which is allowed to stand in the hot until all the chlorine has escaped. For pig iron 20 cubic centimetres of water, an equal quantity of concentrated hydrochloric acid, and 3 or 4 grammes of potassium chlorate is employed. After all the chlorine has escaped the solution is diluted with 25 cubic centimetres of hot water, filtered,

* *Stahl und Eisen*, vol. ix. p. 405. † *Ibid.*, pp. 721–723.

and washed with dilute hydrochloric acid. The ferric oxide is then reduced, preferably by sodium hypophosphite, the reduction being effected at a boiling heat. The salt is added in the solid form, and some time must be allowed for the reaction, as it is not instantaneous. The solution is then cooled down to 30° C., and 10 to 20 cubic centimetres of a solution of ammonium thiocarbamate is added, and the solution stirred until the precipitate has collected together. It is then filtered, and washed with dilute hydrochloric acid and water. The precipitate with the filter-paper is then placed in a small beaker and oxidised in the hot with 10 cubic centimetres of strong nitric acid. When the oxidation is complete 20 cubic centimetres of water is added, and the solution is filtered through a small filter-paper, and washed with hot water. It is then supersaturated with ammonia, and the solution cooled down. If, on the other hand, ammonium thiocarbonate is used the solution is cooled but slightly, and then from 2 to 5 cubic centimetres of the sulfocarbonate solution is added, and the whole stirred vigorously for thirty seconds. The precipitate is filtered off rapidly, and is washed with hot dilute hydrochloric acid and hot water. The precipitate is then treated with about 10 cubic centimetres of concentrated ammonia, and the filter-paper washed out with dilute ammonia. To the solution 10 cubic centimetres of pure hydrogen peroxide is added, and the whole heated nearly to boiling for about a quarter of an hour, and then cooled rapidly. The solution obtained either by this method or by that previously described, contains the arsenic in the form of arseniate. Ten cubic centimetres of concentrated ammonia, and an equal quantity of magnesia mixture are then added, and, if thiocarbonate has been used, a similar quantity of 33 per cent. ammonium chloride solution. The solution is well stirred, allowed to stand, filtered, washed, the precipitate dissolved in dilute nitric acid, evaporated to dryness in a crucible, and then ignited and weighed.

The ammonium thiocarbamate is produced in the following manner:— The ammonia produced from a mixture of 150 parts of ammonium chloride and 300 parts of caustic lime is passed into 600 parts of alcohol of 95 per cent. strength, and to this solution 96 parts of carbon disulphide is added. On cooling, almost the whole of the salt crystallises out. It is collected on a filter-paper, washed with a little alcohol, and dried between other filter-papers. For precipitation purposes a 5 per cent. solution is employed. Ammonium thiocarbonate is best made by the continued shaking of a mixture of half a litre of concentrated ammonia and 50 cubic centimetres of carbon disulphide.

As this solution is still strongly alkaline, the solution containing the arsenic acid to be determined must be made strongly acid before adding the thiocarbonate.

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## II.—*ANALYSIS OF IRON ORES AND SLAG.*

**Titration of Iron.**—Mr. D. J. Carnegie* has made a series of researches on the nature of the reaction between solutions of ferric chloride and potassium iodide and the volumetric titration of iron in a ferric state. He concludes that there is not a simple interchange of molecules and liberation of iodine as expressed in the equation

$$FeCl_3+KI=FeCl_2+KCl+I,$$

but that there is a series of complicated reactions and interchanges which finally give this result.

**Reduction of Ferric Sulphate.**—For the proper titration of iron by permanganate, all the iron must be reduced, and there must be no zinc left undissolved. Mr. C. Jones † finds that ferric solutions are very rapidly reduced by filtration through pulverised zinc. His apparatus consists of two cups connected by a three-way cock with a tube containing pulverised zinc. The lower end of the tube is provided with a stopper, ground to fit the titrating flask, and having a tube leading to a filter-pump. The tube is four-fifths filled with 300 grammes of zinc which is fine enough to pass a forty mesh, but not a sixty mesh sieve. A plug of glass wool at the lower end of the tube acts as a filter. The zinc will last sixty operations, and should be first washed with dilute sulphuric acid. A vacuum of 5 to 6 lbs. should be used, as the generation of hydrogen prevents easy filtration. The ferric solution is run through from the cups, and the apparatus is rinsed with water five times, each reduction taking two minutes. Dilute solutions must be used with not more than 50 cubic centimetres of sulphuric acid in 300 cubic centimetres of ferric solution. The reduced solution measures about 400 cubic centimetres, and has a temperature of about 40° C.

The author then gives the results of some titrations and retitrations showing the small amount of iron introduced by solution of the zinc.

* *The Chemical News*, vol. lx. pp. 87–90.
† *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 411–419.

He also shows that there is less error due to this cause than is generally believed.

Mr. J. K. Eveleth has successfully used pulverised zinc in a platinum cage. If copper is largely present in the ores it will be reduced, and stop the action. Mr. Jones points out that the zinc can readily be changed, or an arrangement of zinc plates might be used.

**The Determination of Zinc in Iron Ores.**—B. Platz * points out that hitherto there has been no rapid method for the determination of zinc in iron ores. The usual method consists in precipitating the iron by sodium acetate, and then, after the addition of acetic acid to the solution, the zinc by the aid of sulphuretted hydrogen. This method involves a very tiresome filtration of large quantities of the basic iron acetate, which it is difficult, if not impossible, to wash properly, and which may consequently prove a grave source of error if only small quantities of ore are available for analysis. Again, Hampe has shown that a considerable quantity of zinc passes into the iron precipitate, which necessitates its re-solution and precipitation. The sulphuretted hydrogen method of Rose's text-book is only accurate when the zinc is present in quantities exceeding 20 per cent. of that of the iron also in the solution. The author therefore describes the following method, which he has found will enable a complete separation of the zinc to be effected :—

Five grammes of the ore is dissolved in concentrated hydrochloric acid. When the solution is complete, 2 or 3 cubic centimetres of concentrated nitric acid is added, and the whole evaporated to dryness, taken up, and then filtered. The filtrate is acidulated, heated to from 80° to 100°C., and sulphuretted hydrogen is bubbled through. By this means any copper, arsenic, or antimony present is precipitated, and ferric chloride is converted into the ferrous salt. The solution, which should be at least 200 cubic centimetres in volume, is saturated with sulphuretted hydrogen, and, if the copper is to be determined, filtered. If, however, this is not required, acetic acid and ammonium acetate are added, and ammonia is also added very carefully until the precipitate it produces has become of a grey colour. This precipitate consists of zinc sulphide with a little iron sulphide. If after well stirring the grey colour is found not to disappear, add water acidulated with hydrochloric acid until the precipitate has become white, then add again dilute ammonia until a constant light grey colour has been pro-

* *Stahl und Eisen*, vol. ix. pp. 494–496.

duced. Allow to settle, filter, and wash with sulphuretted hydrogen water. If the precipitation is complete, a further addition of ammonia to the filtrate will only produce a slight precipitate of iron sulphide on the surface, which will disappear on stirring. The filter paper and its contents are placed in a beaker, dissolved in dilute hydrochloric acid, filtered if necessary, and washed with sulphuretted hydrogen water. The filtrate is then heated to expel the sulphuretted hydrogen, sodium carbonate is added in slight excess, the solution heated to boiling, filtered, the precipitate of basic zinc carbonate dried, and then ignited in the ordinary manner.

## III.—*FUEL ANALYSIS.*

**Estimation of Sulphur in Coal.**—Dr. G. H. Bailey * reviews the methods at present in use for determining the percentage of sulphur in coal, and compares recognised results with experiments carried out on a large scale. Oxidation by chlorate or nitre and by aqua regia invariably yield too low results. There is a difficulty in using such large amounts of material, which must be perfectly pure, and the precipitation by barium is incomplete when the solution contains large amounts of alkaline salts. The method recommended is to use a mixture of two parts of magnesia and one of sodium carbonate in the combustion of the coal. Exhaust the mass with water, oxidise with bromine water, acidulate with hydrochloric acid, and precipitate the sulphur as basic sulphate. The results are fairly constant, and are about one-third higher than by the usual methods. Lime may be used instead of magnesia, but gives more trouble from the insolubility of calcium sulphate.

Experiments were made on a large scale by collecting samples of boiler furnace gases from several varieties of coal to find out the distribution of the sulphur after combustion. Full details are given in tabular form, and show that only part of the sulphur is carried off by the flues. Some remains in the clinkers, ash, and flue-dust, but even then a large proportion is unaccounted for except by the supposition that it attacks the boiler plates. Sulphates, mixed with coal before combustion, remain with the ash. The behaviour of sulphur during the distillation of coal is variable. In some cases very little comes over during the earlier stages; in others the reverse happens.

* *The Journal of the Society of Chemical Industry*, vol. viii. pp. 360–365.

# STATISTICS.

## *CONTENTS.*



## I.—*UNITED KINGDOM.*

**Iron Ore.**—The production of stratified ironstone from coal mines in the United Kingdom during 1888 amounted, according to the official statistics,* to 8,635,032 tons, valued at £1,838,844. The amount of metal obtainable from this ore is 2,590,510 tons. The amount of iron ore raised was 2,937,253 tons, valued at £1,317,021. The amount of iron ore obtained from open works was 3,018,428 tons, valued at £345,452. The total production of all classes of iron ore was therefore 14,590,713 tons, valued at £3,501,317.

**Pig Iron.**—The number of ironworks in operation in 1888 amounted to 150. There were 836 blast furnaces, of which number 424 were in blast. The amount of pig iron made was 7,998,969 tons, and in its manufacture there was used 19,152,074 tons of iron ore, and 16,131,267 tons of coal.

**Iron Trade Statistics.**—According to the returns made to the British Iron Trade Association, the production of pig iron in the United Kingdom during the first half of 1889 amounted to 4,083,597 tons, being an increase in make of 87,767 tons as compared with the

* "Mineral Statistics of the United Kingdom for the Year 1888. Prepared by Her Majesty's Inspectors of Mines." London, 1889.

previous half year. The production of Bessemer steel ingots during the first half of 1889 was 1,043,256 tons; that of Bessemer steel rails was 468,325 tons. The production of open-hearth steel during the same period was 750,721 tons.

**Imports and Exports.**—According to the Board of Trade returns, the imports of iron ore, iron, and steel into the United Kingdom during the first half of 1889 were as follows:—

| | Tons. |
|---|---|
| Iron ore | 2,161,459 |
| Bar, angle, bolt, and rod iron | 37,301 |
| Steel, unwrought | 4,501 |
| Girders, beams, and pillars | 38,756 |
| Unenumerated | 73,458 |

The exports during the same period were as follows:—

| | Tons. |
|---|---|
| Pig iron | 508,559 |
| Bar, angle, bolt, and rod iron | 136,796 |
| Railroad of all sorts (including 368,900 tons of steel rails) | 527,860 |
| Wire of iron and steel, and manufactures thereof, except telegraph wire | 27,796 |
| Hoops, sheets, boiler and armour plates, including galvanised sheets | 189,786 |
| Tin plates and sheets | 224,473 |
| Cast and wrought iron, and all other manufactures unenumerated except ordnance | 235,120 |
| Old iron and steel for remanufacture | 58,629 |
| Unwrought steel | 70,517 |
| Manufactures of steel, or steel and iron combined | 11,365 |
| Total | 1,990,901 |
| Total value | £13,834,478 |

During the first half of 1889 there were exported 13,781,639 tons of coal, cinders, and manufactured fuel. The value was £6,874,926. The corresponding amount for the first half of 1888 was 12,420,119 tons, with a value of £4,776,090, and for the first half of 1887 the amount was 11,364,174 tons, with a value of £4,776,090.

**Coal Resources of Great Britain.**—The present and future conditions of our coal supply are considered by Prof. E. Hull.* The output at the beginning of the century probably did not exceed 10,000,000 tons, a very large proportion being drawn from the Newcastle district. In 1830 the total production of the British Isles rose to 29,000,000 tons, and to over 80,000,000 tons in 1860, while

* Paper read before the Economic Science Section of the British Association at the Newcastle-upon-Tyne meeting, 1889.

in 1888 the output reached 170,000,000 tons. There seems reason for believing that the output had been doubled during each quarter of a century. In 1860 the author calculated that there was sufficient coal, not deeper than 4000 feet, to last for 1000 years at the then rate of production. Since then the reserves have been reduced by 3,650,000,000 tons, an amount which, though great, has not materially affected our coal resources. The production of the South Wales coalfield had doubled between 1854 and 1879, and amounted to 27,355,000 tons in 1888, largely owing to the demand for steam coal in the Cardiff district. The resources of this basin are enormous, and the Lancashire, Cheshire, Yorkshire, and Nottingham coalfields are highly progressive, as are also the Northumberland and Durham fields. The great northern field, notwithstanding the long period during which it has been worked, shows no signs of falling off.

The discovery of ironstone in the Cleveland district, and the great exports from the northern ports, have given a vast impetus and caused an enormous drain, but there is sufficient coal left in the district to produce at the present rate for three centuries. The relation of the iron deposits in the North Riding, in North Lancashire and Cumberland, was then considered in relation to the coal production, and the different coalfields were passed in review to show which were progressive, and which were stationary or retrogressive. Finally, the author was of opinion that the enormous output has not seriously crippled our resources, but that there is likely to be a general rise in the value of coal in the near future, owing to the greater depth and increased cost of mining. Reference was made to coal mining in America, and the author agreed with Prof. Jevons that we cannot expect an importation of coal from the United States when our own becomes scarce. In the discussion which followed the paper, Mr. S. Bourne pointed out our large export of some 20,000,000 tons per annum as a serious drain. The large discoveries in various parts of the world, greater facilities in transit, more extended use of petroleum and water power, would all help the present reserves to hold out.—Mr. J. Morley thought that the author had not taken thin seams into sufficient consideration in his estimates, and pointed out the economies in the iron and steel trades, but this is more than counterbalanced by the greatly increased production of iron.

## II.—*AUSTRIA-HUNGARY.*

**Mineral Statistics.**—The following are the official returns relating to the production of the mines and works of the Austrian Empire, exclusive of Hungary, during the year 1888: *—

| Divisions. | Iron Ore. | Forge Pig Iron. | Foundry Pig Iron. | Total Pig Iron. | Per cent. of Total Pig Iron Production. |
|---|---|---|---|---|---|
| | Metric Tons. | Metric Tons. | Metric Tons. | Metric Tons. | Metric Tons. |
| Bohemia | 355,086 | 116,466 | 20,827 | 137,293 | 23·42 |
| Lower Austria | 6,148 | 43,824 | 5,162 | 48,986 | 8·36 |
| Salzburg | 6,573 | ... | 2,486 | 2,486 | 0·42 |
| Moravia | 30,886 | 124,249 | 29,513 | 153,762 | 26·23 |
| Silesia | 2,633 | 40,738 | 3,657 | 44,395 | 7·58 |
| Styria | 511,934 | 147,019 | 2,130 | 149,149 | 25·45 |
| Carinthia | 72,811 | 39,457 | 840 | 40,297 | 6·88 |
| Tyrol | 4,865 | 1,734 | 1,362 | 3,096 | 0·53 |
| Carniola | 9,545 | 3,331 | 570 | 3,901 | 0·66 |
| Galicia | 8,839 | ... | 2,756 | 2,756 | 0·47 |
| Totals | 1,009,320 | 516,818 | 69,303 | 586,121 | 100·00 |

The following divisions of the Empire showed an increased production of pig iron as compared with that of the preceding year:—

| Divisions. | Metric Tons. | Per cent. |
|---|---|---|
| Bohemia | 11,954 | 9·53 |
| Lower Austria | 17,198 | 54·10 |
| Salzburg | 1,085 | 77·40 |
| Moravia | 3,536 | 2·35 |
| Silesia | 8 | 0·02 |
| Styria | 38,685 | 35·02 |
| Carinthia | 1,253 | 3·21 |
| Tyrol | 1,754 | 130·65 |
| Galicia | 169 | 6·53 |

The production in Carniola diminished by 1298 tons, or 24·97 per cent.

Of the 125 existing blast-furnaces, 67 were in blast for 2969 weeks. At the ironworks 10,909 workpeople were employed, and at the iron ore mines 4404.

The production of coal in the Austrian Empire, excluding Hungary,

* *Statistisches Jahrbuch des k.k. Ackerbauministeriums für 1888.*

amounted in 1888 to 8,274,461 tons, valued at £1,997,526; the production of lignite being 12,860,255 tons, valued at £1,728,423. The coke produced amounted to 567,826 tons, valued at £326,449. Of graphite 19,646 tons, valued at £52,895, were produced.

The manganese ore produced amounted to 6554 tons, valued at £8099.

**Bosnia.**—The British Consul at Lerajevo reports that the Bosnian Mining Company last year closed their manganese mines at Cevljanovic as prices were too low. The chrome mines at Dubostica produce two or three thousand tons annually, but the mines in the immediate neighbourhood are getting worked out. There appears to be abundance of chrome ore in Bosnia.*

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## III.—*BELGIUM.*

**Coal.**—The production of coal in Belgium † amounted to 19,218,481 tons in 1888, as compared with 18,378,624 tons in 1887, showing an increase of 839,857 tons. The aggregate value was £6,480,723 for 1888, as compared with £5,906,962 in the previous year. The production by provinces was as follows:—

| | 1888. | Mines Working in 1888. |
|---|---|---|
| | Tons. | |
| Hainaut | 13,993,140 | 184 |
| Namur | 428,173 | 13 |
| Liége | 4,797,168 | 71 |
| Total | 19,218,481 | 268 |

The number of workpeople employed was 103,477, and the average annual wages was £34, 15s.

**Imports and Exports.**—The imports of iron, steel, coal, &c., during the first six months of 1889, compared with those for the corresponding period of 1888, were as follows:—

* *Engineering*, vol. xlviii. p. 315.

† *Industries*, vol. vii. p. 256.

*Statistics of Belgian Exports and Imports of Metals and Minerals.*

| | Exports. | | Imports. | |
|---|---|---|---|---|
| | 1889. | 1888. | 1889. | 1888. |
| | Tons. | Tons. | Tons. | Tons. |
| Steel blooms | 1,830 | 2,850 | 950 | 587 |
| Steel rails | 35,079 | 28,041 | 251 | 168 |
| Steel bars, plates, and wire | 11,130 | 14,582 | 1,459 | 1,252 |
| Wrought steel | 2,469 | 1,368 | 666 | 234 |
| Pig iron | 3,516 | 5,212 | 118,693 | 111,779 |
| Old iron | 2,947 | 386 | 12,976 | 15,919 |
| Iron wire | 2,386 | 2,203 | 1,751 | 1,759 |
| Iron rails | 3,169 | 5,408 | 159 | 119 |
| Plates | 26,412 | 20,761 | 874 | 632 |
| Other kinds of iron | 118,622 | 110,032 | 7,185 | 3,791 |
| Nails | 6,026 | 6,007 | 252 | 273 |
| Wrought iron | 15,871 | 11,172 | 2,039 | 2,133 |
| Castings | 10,754 | 8,677 | 785 | 387 |
| Totals | 240,211 | 216,699 | 148,040 | 139,033 |
| Iron ore | 77,813 | 76,113 | 935,995 | 837,092 |
| Coal | 1,900,090 | 1,915,717 | 491,315 | 473,107 |
| Coke | 583,101 | 498,310 | 8,049 | 11,762 |
| Patent fuel | 159,771 | 170,676 | ... | ... |

## IV.—*CHINA.*

**Imports in 1888.**—Mr. E. M'Kean, the Secretary for Statistics of the Chinese Maritime Custom-houses, reports that in 1888 there was imported into China 77,000 tons of iron, an increase of 18 per cent. over the quantity imported in 1887. The quantity of petroleum imported was 16,613,090 gallons, as compared with 12,015,135 in 1887, and 24,038,101 in 1886.

The net import trade of China * for 1888 amounted to £26,000,000, as against £23,500,000 in 1887. The imports of metals amounted to £1,750,000, of which iron contributed £540,000. The iron imported consisted chiefly of rail, rod, bar, and old iron to meet the demand in small workshops.

* *Industries*, vol. vii. pp. 402–403.

## V.—*FRANCE.*

**Iron and Steel.**—The production of pig iron for the first half of 1889 is stated to have been as follows :*—

| Description. | Forge Pig Iron. | Foundry Pig Iron. |
|---|---|---|
| | Tons. | Tons. |
| Coke pig iron . . . . . | 644,259 | 201,935 |
| Charcoal pig iron . . . . | 3,643 | 1,025 |
| Mixed brands . . . . . | ... | 2,955 |
| Totals . . . . . | 647,902 | 205,915 |
| Totals in first half of 1887 . | 651,982 | 169,842 |
| Increase or decrease . . | −4,080 | +36,073 |

The total production of pig iron thus amounted to 853,817 metric tons, against 821,824 tons in the first half of 1888, the increase being 31,993 tons.

The production of manufactured iron was as follows :—

| Description. | First Half 1889. | First Half 1888. | Increase or Decrease. |
|---|---|---|---|
| | Tons. | Tons. | Tons. |
| Puddled rails . . . . . . | 273 | 219 | +54 |
| Merchant iron, puddled . . . | 264,272 | 288,529 | ... |
| " " charcoal . . . | 3,897 | 4,788 | ... |
| " " obtained by reheating | 65,463 | 81,644 | ... |
| Total merchant iron . | 333,632 | 374,961 | −41,329 |
| Plates, puddled . . . . . | 49,110 | 46,348 | ... |
| " charcoal . . . . . | 937 | 1,733 | ... |
| " by reheating . . . . | 3,513 | 4,815 | ... |
| Total plates . . . | 53,560 | 52,896 | +664 |
| Total production . . | 387,465 | 428,076 | −40,611 |

* *Bulletin du Comité des Forges*, No. 249, pp. 58–62.

The French production of steel over the same period was as follows:—

| Description. | First Half 1889. | First Half 1888. | Increase or Decrease. |
|---|---|---|---|
| | Tons. | Tons. | Tons. |
| Rails, Bessemer . . . . | 75,412 | 83,538 | ... |
| „ open-hearth . . . | 3,549 | 3,537 | ... |
| Total rails . . . | 78,961 | 87,075 | - 8,114 |
| Merchant steel, Bessemer . . | 52,529 | 46,905 | ... |
| „ „ open-hearth . | 54,794 | 41,796 | ... |
| „ „ puddled . . | 12,177 | 13,061 | ... |
| „ „ cement . . | 776 | 686 | ... |
| „ „ crucible . . | 5,493 | 4,304 | ... |
| Total merchant steel . | 125,769 | 106,752 | + 19,017 |
| Plates, Bessemer . . . | 15,192 | 17,925 | ... |
| „ open-hearth . . . | 21,820 | 22,655 | ... |
| „ miscellaneous . . | 4,346 | 5,217 | ... |
| Total plates . . | 41,358 | 45,797 | - 4,439 |
| Total steel . . | 246,088 | 239,624 | + 6,464 |

**Coal.**—The output of the French collieries is stated * to have been as follows:—

| Description. | First Half 1889. | First Half 1888. | Increase or Decrease. |
|---|---|---|---|
| | Tons. | Tons. | Tons. |
| Coal and anthracite . . . . | 11,696,020 | 10,860,925 | + 835,095 |
| Lignite . . . . . . | 210,954 | 216,796 | - 5,842 |
| Totals . . | 11,906,974 | 11,077,721 | + 829,253 |

**Imports and Exports.**—The French imports and exports of iron ore, iron, and steel are stated † to have been as follows:—

* *Bulletin du Comité des Forges*, No. 249, pp. 55-57. † *Ibid.*, No. 249, pp. 51-52.

| Description. | Imports during the First Half of | | Exports during the First Half of | |
|---|---|---|---|---|
| | 1889. | 1888. | 1889. | 1888. |
| Iron ore | 641,003 | 567,431 | 112,397 | 144,185 |
| Pig iron | 9,167 | 12,826 | 25,993 | 15,471 |
| Manufactured iron | 5,773 | 7,281 | 45,432 | 15,929 |
| Steel | 2,156 | 2,649 | 13,396 | 6,596 |

Of iron imported and exported after manufacture, the tonnage was as follows:—

| Description. | Imports during the First Half of | | Re-exports during the First Half of | |
|---|---|---|---|---|
| | 1889. | 1888. | 1889. | 1888. |
| Forge pig iron | 25,631 | 42,043 | 21,733 | 33,107 |
| Foundry pig iron | 29,466 | 19,509 | 27,237 | 14,234 |
| Totals | 55,097 | 61,552 | 48,970 | 47,341 |
| Charcoal iron | 1,530 | 781 | 1,960 | 847 |
| Coke iron | 2,653 | 2,747 | 1,965 | 2,654 |
| Plates | 2,035 | 1,764 | 1,464 | 1,954 |
| Totals | 6,218 | 5,292 | 5,389 | 5,455 |
| Steel | 2,420 | 2,584 | 1,068 | 1,121 |

The total amount of the imports of iron and steel during the first half of 1889 was 80,831 tons, that is, 11,353 tons, or 12·40 per cent. less than the corresponding figure for 1888.

**The Iron Industry of France.**—The ironworks of France may be grouped in four districts—the North, with such works as Anzin, Denain, Marchiennes, Maubeuge, Marquise, Fiveslille; the Centre, with Creuzot, Commentry, St. Chamond, Firminy, Fourchambault; the South, with La Voulte, Bessèges, St. Louis; and the East, with Longwy, Pont-à-Mousson, Stenay, and St. Dizier. The following tables relating to the iron trade of France are grouped according to these districts:—

*Output of Coal in* 1888.

| Districts. | Metric Tons. |
|---|---|
| North— | |
| Nord and Pas de Calais | 12,364,085 |
| Centre— | |
| Loire | 3,357,817 |
| Saône-et-Loire | 1,611,057 |
| Allier | 988,529 |
| Isère | 128,700 |
| Cher | ... |
| South— | |
| Gard | 1,827,707 |
| Aveyron | 809,567 |
| Other districts | 1,293,351 |
| Total | 22,380,813 |

The production of pig iron was as follows :—

*Production of Pig Iron in France in* 1882, 1887, *and* 1888.

| Districts. | 1882. | 1887. | 1888. |
|---|---|---|---|
| North— | | | |
| Nord | 255,322 | 223,315 | 231,693 |
| Pas-de-Calais | 53,126 | 97,920 | 85,391 |
| Totals | 308,448 | 321,235 | 317,084 |
| Centre— | | | |
| Loire | 58,547 | 31,536 | 34,161 |
| Saône-et-Loire | 177,740 | 55,001 | 70,107 |
| Allier | 90,507 | 28,151 | 18,090 |
| Rhône | 89,437 | 8,700 | 14,368 |
| Cher | 17,959 | 4,590 | 14,525 |
| Isère | 36,763 | 13,307 | 13,945 |
| Totals | 470,953 | 141,285 | 165,196 |
| South— | | | |
| Gard | 144,818 | 73,789 | 54,994 |
| Aveyron | 33,388 | 6,746 | 6,465 |
| Ardèche | 103,316 | 47,214 | 37,933 |
| Bouches-du-Rhône | 25,739 | 13,536 | 21,250 |
| Ariège | 22,150 | 9,632 | 7,364 |
| Totals | 329,411 | 150,917 | 128,006 |
| East— | | | |
| Meuse | 9,767 | 5,762 | 3,090 |
| Meurthe-et-Moselle | 716,043 | 770,842 | 911,009 |
| Haute-Marne | 82,865 | 63,148 | 43,589 |
| Ardennes | 22,258 | 18,298 | 20,475 |
| Totals | 830,933 | 858,050 | 978,163 |

The quantity of charcoal pig iron made in 1888 was 22,792 tons, nd of foundry iron 382,046 tons.

The following table shows the production of rolled iron in the same districts :—

*Production of Rolled Iron in France in* 1882, 1887, *and* 1888.

| Districts. | 1882. | 1887. | 1888. |
|---|---|---|---|
| North— | | | |
| Nord . . . . . | 335,442 | 285,631 | 303,541 |
| Pas-de-Calais . . . | 308 | 325 | 430 |
| Totals . . . | 335,750 | 285,956 | 303,971 |
| Centre— | | | |
| Loire . . . . . . | 84,280 | 37,361 | 37,111 |
| Saône-et-Loire . . . | 64,949 | 68,126 | 71,564 |
| Allier . . . . . . | 38,378 | 29,360 | 31,631 |
| Cher . . . . . . | 570 | 560 | 627 |
| Isère . . . . . . | 14,833 | 5,155 | 4,009 |
| Nièvre . . . . . . | 20,373 | 5,049 | 6,672 |
| Totals . . . | 223,383 | 145,611 | 151,614 |
| South— | | | |
| Gard . . . . . . | 27,916 | 14,870 | 14,103 |
| Aveyron . . . . | 19,986 | 11,562 | 10,200 |
| Bouches-du-Rhône . . | 1,567 | 880 | 1,457 |
| Ariège . . . . . . | 16,537 | 6,361 | 5,331 |
| Totals . . . | 66,006 | 33,673 | 31,091 |
| East— | | | |
| Meuse . . . . . . | 20,103 | 7,993 | 10,717 |
| Meurthe-et-Moselle . . | 49,111 | 42,168 | 42,368 |
| Haute-Marne . . . | 90,773 | 61,657 | 88,718 |
| Ardennes . . . . . | 79,961 | 64,290 | 67,851 |
| Totals . . . | 239,948 | 176,108 | 209,654 |

The following table shows the production of steel rails during the years 1882, 1887, and 1888 : *—

| Districts. | 1882. | 1887. | 1888. |
|---|---|---|---|
| | Metric Tons. | Metric Tons. | Metric Tons. |
| North . . . . . . | 59,529 | 114,620 | 94,863 |
| Centre . . . . . . | 170,208 | 4,747 | 5,098 |
| South . . . . . . | 106,461 | 32,145 | 23,481 |
| East . . . . . . . | ... | 25,183 | 21,818 |
| Landes . . . . . . | ... | 26,113 | 30,313 |
| Total product . | 336,198 | 202,808 | 175,573† |

* *Iron Age*, vol. xliv. p. 370. † 175,598 in original.

The following table shows the progress of the steel trade of France since 1882:—

*Production of Steel in France in* 1882, 1887, *and* 1888.

| Districts. | 1882. | 1887. | 1888. |
|---|---|---|---|
| North— | | | |
| Nord | 61,853 | 87,664 | 95,212 |
| Pas-de-Calais | ... | 61,462 | 50,985 |
| Totals | 61,853 | 149,126 | 146,197 |
| Centre— | | | |
| Loire | 132,529 | 54,536 | 67,619 |
| Saône-et-Loire | 101,320 | 45,519 | 48,746 |
| Allier | 23,301 | 11,527 | 10,360 |
| Isère | 8,739 | 4,321 | 3,859 |
| Nièvre | 5,731 | 9,897 | 9,072 |
| Totals | 271,620 | 125,800 | 139,653 |
| East— | | | |
| Meuse | 51 | 5,558 | 6,155 |
| Meurthe-et-Moselle | 1,616 | 41,265 | 37,814 |
| Haute-Marne | ... | 9,160 | 16,327 |
| Ardennes | 171 | 18,218 | 21,096 |
| Totals | 1,838 | 74,201 | 81,392 |
| South— | | | |
| Gard | 83,579 | 40,534 | 34,722 |
| Aveyron | 25,803 | ... | ... |
| Ariège | 6,223 | 3,496 | 2,087 |
| Totals | 115,605 | 44,030 | 36,809 |

## VI.—*GERMANY.*

**Production of Pig Iron.**—The following table shows the production of pig iron in Germany during the first half of 1889 * :—

| | Metric Tons. |
|---|---|
| Forge pig iron and spiegeleisen | 981,806 |
| Foundry pig iron | 253,355 |
| Acid Bessemer pig iron | 198,704 |
| Basic Bessemer pig iron | 658,511 |
| Total | 2,092,376 |

* Compiled from the statistics published monthly in *Stahl und Eisen.*

The production during the first half of 1888 exceeded the above by nearly 15,000 tons.

**Imports and Exports.**—The following are the returns relating to the iron trade imports and exports into and from the German Customs Union during the first six months of 1889:*—

| Description. | Imports. | | Exports. | |
|---|---|---|---|---|
| | First Half of 1889. | First Half of 1888. | First Half of 1889. | First Half of 1888. |
| | Metric Tons. | Metric Tons. | Metric Tons. | Metric Tons. |
| Iron ore | 608,912 | 578,827 | 1,086,604 | 1,054,678 |
| Pig iron and scrap | 106,332 | 88,968 | 106,629 | 76,538 |
| Malleable iron and steel unmanufactured | 346 | 163 | 10,789 | 11,105 |
| Machines | 18,444 | 17,929 | 34,745 | 36,801 |
| Iron and steel manufactures | 24,587 | 21,208 | 403,853 | 405,568 |

**Iron Trade Statistics of Prussia.**—The official returns ‡ of the production of coal, iron ore, and pig iron in Prussia in 1888 are as follows:—

| Description. | Quantity. | | Value. | |
|---|---|---|---|---|
| | 1887. | 1888. | 1887. | 1888. |
| | Tons. | Tons. | £ | £ |
| Coal | 54,548,283 | 59,475,351 | 13,195,430 | 14,595,946 |
| Lignite | 12,696,487 | 13,207,888 | 1,593,611 | 1,607,967 |
| Iron ore | 3,833,764 | 4,145,254 | 1,089,371 | 1,277,001 |
| Manganese ore | 36,534 | 27,308 | 47,591 | 30,677 |
| Pig iron | 2,863,618 | 3,098,757 | 6,302,376 | 7,141,611 |

**Iron Trade Statistics of Saxony.**—The following are the official statistics relating to the production of fuel, iron ore, iron, and steel in the kingdom of Saxony during the year 1887:§—

* *Stahl und Eisen*, vol. ix. p. 808.

† Compiled from the monthly returns.

‡ *Zeitschrift fur das Berg- Hütten- und Salinenwesen*, vol. xxxvii.

§ *Das Jahrbuch für das Berg- und Hüttenwesen im Königreiche Sachsen auf das Jahr* 1888.

*Output of Metals and Minerals in Saxony.*

| | Metric Tons. |
|---|---|
| Coal and anthracite . . . . . . | 4,293,417 |
| Coke made from the above . . . . . . | 78,646 |
| Lignite . . . . . . . . . | 766,732 |
| Iron ore . . . . . . . . . | 11,680 |
| Manganese ore . . . . . . . . | 469 |
| Foundry pig iron . . . . . . . | 3,191 |
| Bessemer pig iron . . . . . . . | 7,492 |
| Forge pig iron . . . . . . . . | 4,466 |
| Direct castings . . . . . . . . | 99 |

The workpeople employed at the coal mines numbered 18,650, and at the lignite mines 2324. The fatal accidents in coal mines numbered thirty-two, and in lignite mines three. Pig iron was produced at one works only—the Königin Marienhütte, at Cainsdorf.

**Iron Trade Statistics of Upper Silesia.**—Of the forty-four existing blast furnaces in Upper Silesia in 1888, thirty were in blast for a total period of 1392 weeks. The total production of pig iron was as follows :*—

| Description. | 1888. | 1887. |
|---|---|---|
| | Metric tons. | Metric tons. |
| Forge pig iron . . . . . . | 313,305 | 301,325 |
| Foundry pig iron . . . . . . | 20,587 | 20,168 |
| Acid Bessemer pig iron . . . . | 27,965 | 23,846 |
| Basic Bessemer pig iron . . . . | 74,774 | 48,819 |
| Totals . . . . | 436,631† | 394,158† |

The average weekly production of each blast furnace was 315 tons The production shows an increase of 10·93 per cent. over that of the previous year, which, in its turn, exceeded that of the year before by 6·14 per cent. The greatest increase, as will be seen from the table given above, was in the production of basic Bessemer iron, which was more than half as much again as that of 1887.

The home use of Upper Silesian pig iron amounted in 1888 to 430,914 tons, an increase of 46,411 tons, or 12·05 per cent. over that of 1887. On the other hand, the exports of pig iron diminished from 21,583 tons in 1887 to 9457 tons in 1888, a diminution of 56·1 per

* *Stahl und Eisen*, vol. ix. p. 518.

† These totals are 438,481 and 395,264 respectively in the original.

cent., the reason for this decrease being the heavy import duties recently imposed by Russia. Of the above quantity of 9457 tons, 9182 were exported to Russia, and the remainder to Austria. The total value of the pig iron produced was £1,078,196, as compared with £938,849 in 1887.

Twelve blast furnace works use coke as fuel. They possess 163 steam-engines, with 13,096 horse-power. The materials passed through the blast furnace for each ton of pig iron produced were as follows :—

| | 1888. | 1887. |
|---|---|---|
| | Tons. | Tons. |
| Different ores | 2·1222 | 2·2877 |
| Scrap iron and cinder | 0·7061 | 0·5847 |
| Various other additions | 0·9004 | 0·9482 |
| Totals | 3·7287 | 3·8206 |

The percentage yield of iron was 26·81 in 1888, and 26·17 in 1887.

The fuel used in the blast furnaces per ton of pig iron produced was 1·0867 ton, and for other purposes 0·7515 ton, or a total of 1·8382 ton, as compared with 1·9929 ton in 1887.

Considerable quantities of argentiferous lead and other by-products were also produced, and these, with the 41,383 tons of slag sold for road purposes, and 23 tons of slag wool, caused a diminution of 2·15 shillings in the net cost of production of the ton of pig iron. The workpeople employed included 2751 men, 761 women, and 156 children, the total sum paid in wages amounting to £105,187, each man earning on an average £33, 6s., each woman £15, and each child £13, 16s.

Only two small charcoal furnaces were in blast.

The production of the foundries of Upper Silesia in 1888 amounted to 27,929 tons of castings, 6810 tons of which consisted of pipes. In 1887 these totals were respectively 25,494 tons and 6863 tons. The number of foundries of which statistics were obtainable was twenty-four, possessing fifty-one cupolas and nine reverberatory furnaces. The Herbertz cupola was in use at only one of these works. The average quantity of metal melted per charge by each cupola was 5·32 tons, and in each reverberatory furnace 3·11 tons. The pig iron and scrap melted consisted of 30,058 tons, the consumption of coke amounting to 5915 tons, 979 tons of coal being also burnt.

Rolled iron is produced in about thirteen works, and ingot iron and steel in three. They gave employment in 1888 to 10,713 workpeople, and produced 318,773 tons of finished products, besides 8874

tons of ingots, scrap, &c. The pig iron consumed by these works amounted to 473,900 tons, against 438,922 tons in 1887.

Of coke ovens, 144 batteries with 2170 ovens were at work, a large number of different systems being in use. The quantity of coal consumed was 1,461,174 tons. This gave 775,642 tons of lump coke, besides 67,560 tons of coke smalls, 72,800 tons of dust, 3096 tons of tar, and 4930 tons of ammoniacal products. The coal coked, therefore, yielded 62·69 per cent. of coke, of which 84·6 was lump, 7·3 per cent. smalls, and 7·9 per cent. dust. The workpeople employed numbered 2464, more than one-third of whom were women. Of iron ore, 641,096 tons were raised during the year.*

Dr. M. Caspaar† states that in 1888 the sixty-two coal mines of Upper Silesia gave employment to 37,772 male and 4124 female workpeople. The coal raised amounted to 14,445,276 tons, of the value of £2,566,133. The output of coal in Upper Silesia is about double that of the whole of Austria. The coke made amounted to 775,642 tons of lump coke, and 67,520 tons of coke smalls. 8026 tons of tar and ammonia liquor was also obtained.

The iron ore mines at work in Upper Silesia in 1888 numbered fifty-two. The statistics as to the output of ore are not yet complete, but it is known that the quantity reached 641,096 tons, of the total value of £116,422. The workpeople employed numbered 1890 males and 1395 females.

## VII.—*ITALY.*

**Mineral Statistics.**—According to the official statistics,‡ in 1887 there were thirty-six iron mines in operation in Italy. The total production amounted to 230,575 tons of iron ore, valued at £101,106. The number of workmen employed was 1809. There were five manganese mines, employing as a whole 111 workmen, and producing 4434 tons of manganese ore, valued at £4533. There were thirty-two coal mines, which produced 327,665 tons of anthracite and lignite, valued at £100,114, and which afforded employment to 2870 workmen.

**Pig Iron.**—In Italy there were in 1887 twelve furnaces in blast. These produced 12,265 tons of pig iron, and gave employment to 266 workmen.

* *Stahl und Eisen*, vol. ix. pp. 624-626.
† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xxxvii. pp. 334-336.
‡ *Annali di Agricoltura* 1889; *Rivista del servizio minerario nel* 1887.

**Wrought Iron and Steel.**—The production of wrought iron in the year 1887 amounted to 172,834 tons, and that of steel to 73,262 tons, the total being 246,096 tons for the two. The number of workmen employed was 11,714.

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## VIII.—*JAPAN.*

**Iron in Japan.**—In his report upon the trade and shipping of Yokohama during the year 1887, Mr. Quin, the British Consul, states that the value of the imports and exports compares favourably with that of the previous year, the former having been £5,568,633, as compared with £4,131,993, and the latter £5,347,743, as compared with £5,308,136. In metals, the value of the total trade of the port for 1887 exceeded that for 1886 by nearly 40 per cent., and was generally of a satisfactory character, the largest increase being in the following articles:—Iron rails, £101,913, against £86,720 in 1886; iron pipes of the value of £66,299, and ironware, which was imported to the value of £101,324, against £39,427 in 1886; also galvanised and roofing iron of the value of £10,479. Railway extensions are still absorbing a large quantity of rails, most of which, though included in the Customs returns as iron, should be called steel rails. The large import of iron pipes is accounted for by the requirements of Yokohama for a system of waterworks which has been successfully completed, and is not likely to appear again in the returns, unless the scheme talked of for Tokio be decided upon. The increase in ironware is accounted for by the importation of numerous heavy bridges and other ironware connected with railway works. Of the item £33,872 for engines, &c., over £16,000 was for locomotives, thus swelling the railway requirements to about £120,000. The import of galvanised iron, both corrugated and flat, has more than doubled. On the other hand, the consumption of pig iron, tin-plates, and steel has fallen off. Of the pig iron imported, Italy is credited with about 400 tons.

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## IX.—*NATAL.*

**Coal in Natal.**—Steam machinery is employed at the Elandslaagte Colliery only in Natal.* The existence of coal in this district has been known for several years, and it was mined by the military during

* *Natal Witness*, through *Iron and Coal Trades Review*, vol. xxxix. p. 521.

the Zulu War. Out of seven shafts, two only are being worked, with three cages. The deepest shaft is only 45 feet deep. Altogether, 152 hands are employed, and the output is expected to be at about the rate of 2000 tons per month. The district is to be tested for deeper coal by the diamond drill.

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## X.—*NORWAY.*

**Mineral Production of Norway.**—No coal occurs in Norway, and consequently no iron ore is smelted. The Näs puddling works in the district of Nedenäs in 1885 produced 241·569 tons of blooms, 531·204 tons of bar iron, 134·058 tons of tool steel, 146·249 tons of cast steel ingots, and 142·044 tons of manufactured iron made from imported pig iron. The exports of iron ore during 1885 amounted to 1400 tons.

Up to the year 1875 the yearly production of chromium ore amounted to 600 tons. Since that year no more ore has been raised, as it has been found impossible to compete with the supplies from Asia Minor and Turkey.*

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## XI.—*RUSSIA.*

**The Iron Trade Statistics of Russia.**—There were in Russia in 1886,† 128 ironworks producing pig iron. They possessed 192 blast furnaces in blast, 107 of which were provided with hot-blast stoves. The largest relative production was in the Ural, which, with 61 works and 106 blast furnaces produced 344,000 tons of pig iron. In the governments of Perm, Ufa, and Jekaterinoslav the quantities produced were respectively 240,114, 55,102, and 46,994 tons. The works producing wrought iron numbered 190. They had 497 hearths and 622 puddling furnaces, as well as 473 welding and 450 heating furnaces. Besides these, there were in Finland six small blast furnaces producing malleable iron by direct reduction processes, their product having been 668 tons. For finished products the district of the Ural was again the most important, having produced about 200,000 tons, the district of Perm taking the second place.

* *Berg- und Hüttenmännische Zeitung*, vol. xlviii. pp. 271–273.

† Compare *Journal of the Iron and Steel Institute*, vol. i. 1889, p. 422.

**Steel.**—There were in 1888, 34 works which possessed 17 converters, 67 open-hearths, 34 cementation furnaces, and 282 crucible furnaces. From the steel manufactured, 114,000 tons of rails and 9219 tons of plates and sheets were made. The maximum production was in the St. Petersburg district, which produced 75,059 tons, the next important districts being Jekaterinoslav and Warsaw, where the production was, respectively, 46,118 and 25,956 tons.

One half of the bituminous coal produced was obtained from the kingdom of Poland, and the greater part of the remainder from the Donetz basin, which latter was the sole source of the supply of anthracite. Lignite was chiefly obtained from Poland and the Moscow basin. The total quantity raised was 74,399 tons, of which 69,377 were obtained from the government of Kutaïs. The greater portion of the ore raised—54,440 tons—was exported from Batoum and Poti.

The workpeople employed at the iron mines and smelting works numbered 197,488, and at the collieries 33,158.

**Petroleum Exports.**—The petroleum exports from Russia were as follows in 1888, the exports for 1887 being also shown for the purpose of comparison:—

| Description. | 1888. | 1887. |
|---|---|---|
| | Pud. | Pud. |
| Naphtha, crude | 74,000 | 923,000 |
| Vaseline and paraffin | 3,000 | 6,000 |
| Refined petroleum | 26,651,000 | 11,191,000 |
| Lubricating oils, crude | 1,280,000 | 1,663,000 |
| " " refined | 1,421,000 | 1,076,000 |
| Residues | 4,417,000 | 3,211,000 |
| Totals | 33,846,000 | 18,070,000 |

A pud is approximately $36\frac{1}{8}$ lbs. The exports for 1888 show, it will be seen, an increase of about 87 per cent.

The imports of Russian petroleum into British India have increased from 1,577,000 gallons in 1886 to 17,516,000 gallons in 1888–89. These figures compare with the United States imports into India of 29,000,000 gallons in 1886–87, and 20,000,000 gallons in 1888–89.*

* *Journal de St. Pétersbourg*, June 1889.

## XII.—*SPAIN.*

**Mineral Statistics.**—The iron trade statistics of Spain for the year 1887 show that the quantities of minerals and metals produced were as follows: *—

| Description. | Metric Tons. | Value. |
|---|---|---|
| Iron and steel | 288,704 | £1,585,451 |
| Iron ore | 6,796,266 | 820,988 |
| Manganese ore | 1,460 | 1,496 |
| Coal | 1,021,254 | 331,377 |
| Lignite | 17,051 | 8,385 |
| Briquettes and coke | 134,536 | 431,635 |

**Exports of Pig Iron and Iron Ore.**—The *Bilbao Maritima y Comercial* states that the exports of pig iron and iron ore from Spain in the years 1886, 1887, and 1888 have been as follows :—

| Description. | 1886. | 1887. | 1888. |
|---|---|---|---|
| | Metric Tons. | Metric Tons. | Metric Tons. |
| Pig iron | 49,420 | 115,359 | 73,677 |
| Iron ore | 4,187,527 | 5,215,713 | 4,563,779 |

The exports of iron and iron ore from Spain during the first six months of 1889 were as follows, the figures for the corresponding periods of 1887 and 1888 being also given :—

| Description. | 1889. | 1888. | 1887. |
|---|---|---|---|
| | Metric Tons. | Metric Tons. | Metric Tons. |
| Iron ore | 2,656,171 | 2,375,875 | 2,713,763 |
| Pig iron | 28,900 | 34,863 | 59,288 |

**Accidents in Spanish Mines.**—In 1887 there were employed at iron mines in Spain, 3001 workpeople. The accidents number 53, the killed numbering 16, and the injured 46. In coal mines 6322 workpeople were employed, and of these 14 were killed and 645 injured,

* *Revista Minera*, vol. xl. p. 219.

the total number of accidents amounting to 306; only one death was due to an explosion of fire-damp.*

## XIII.—*UNITED STATES.*

**Production of Pig Iron.**—The following statistics relating to the production of pig iron in the United States in the first six months of 1889 have been prepared by the American Iron and Steel Association:—

*Total Production of Pig Iron.*

| States. | Production in Tons of 2000 lbs. (includes Spiegeleisen). | | |
|---|---|---|---|
| | First Half of 1888. | Second Half of 1888. | First Half of 1889. |
| Maine . . . . . . | 2,550 | 3,024 | 2,700 |
| Massachusetts . . . . . | 7,005 | 6,243 | 2,651 |
| Connecticut . . . . . | 10,236 | 11,408 | 12,108 |
| New York . . . . . | 134,900 | 122,280 | 144,613 |
| New Jersey . . . . . | 50,393 | 51,489 | 67,749 |
| Pennsylvania . . . . . | 1,630,845 | 1,958,341 | 2,012,804 |
| Maryland. . . . . . | 6,250 | 11,356 | 10,233 |
| Virginia . . . . . . | 92,495 | 104,901 | 112,328 |
| N. Carolina . . . . . | 1,100 | 1,300 | 922 |
| Georgia . . . . . . | 23,658 | 15,739 | 11,338 |
| Alabama . . . . . . | 169,696 | 279,796 | 364,346 |
| Texas . . . . . . | 2,968 | 3,619 | 1,411 |
| West Virginia . . . . . | 45,601 | 49,658 | 72,775 |
| Kentucky. . . . . . | 21,267 | 35,523 | 23,865 |
| Tennessee . . . . . | 122,817 | 145,114 | 147,401 |
| Ohio. . . . . . . | 528,536 | 575,282 | 602,476 |
| Indiana . . . . . . | 7,300 | 7,960 | 7,806 |
| Illinois . . . . . . | 294,520 | 284,787 | 282,153 |
| Michigan . . . . . . | 106,578 | 106,673 | 100,363 |
| Wisconsin . . . . . | 51,477 | 64,560 | 74,065 |
| Missouri . . . . . . | 60,789 | 30,994 | 42,795 |
| Minnesota † . . . . . | ... | ... | ... |
| Colorado . . . . . . | 11,522 | 9,355 | ... |
| Oregon . . . . . . | ... | 2,509 | 5,426 |
| California ‡ . . . . . | ... | ... | ... |
| Washington Territory . . | ... | 4,093 | 5,571 |
| Totals . . | 3,382,503 | 3,886,004 | 4,107,899 |
| Anthracite . . . . . | 955,448 | 970,281 | 917,611 |
| Charcoal . . . . . . | 278,238 | 320,551 | 306,780 |
| Bituminous . . . . . | 2,148,817 | 2,595,172 | 2,883,508 |
| Totals . . | 3,382,503 | 3,886,004 | 4,107,899 |

* *Revista Minera*, vol. xl. p. 221. † A blast furnace building. ‡ Furnace idle.

*Total Production of Bessemer Pig Iron.*

| States. | Production in Tons of 2000 lbs. (includes Spiegeleisen). | | |
| --- | --- | --- | --- |
| | First Half of 1888. | Second Half of 1888. | First Half of 1889. |
| New York | 18,732 | 33,342 | 29,233 |
| New Jersey | 14,585 | 12,820 | 13,946 |
| Pennsylvania | 746,479 | 1,024,065 | 990,239 |
| West Virginia | 38,557 | 45,576 | 63,042 |
| Tennessee | 2,315 | ... | ... |
| Ohio | 138,828 | 197,927 | 207,407 |
| Illinois | 275,675 | 275,401 | 247,101 |
| Missouri | 54,144 | 22,376 | 37,080 |
| Michigan | 3,000 | ... | ... |
| Wisconsin | 17,136 | 17,400 | 1,625 |
| Colorado | 10,478 | 5,566 | ... |
| Totals | 1,319,929 | 1,634,473 | 1,589,673 |

The quantity of spiegeleisen and ferromanganese made in the first half of 1888 was 21,162 tons (of 2000 lbs.); in the second half, 33,607 tons; in the first half of 1889, 34,760 tons.

The total stocks of pig iron at June 30, 1889, amounted to 563,286 tons.

**Bessemer Steel Production.**—The American Iron and Steel Association has received from the manufacturers complete statistics of the production of Bessemer steel ingots and Bessemer steel rails in the United States in the first half of 1889.* The following table shows the production of Bessemer steel ingots in the first half of 1889 compared with the production in each half of 1888. The production of steel ingots by the Clapp-Griffiths process is included, but a statement is also added of the ingots produced by this process alone:—

| Ingots. | First Half of 1888. | Second Half of 1888. | First Half of 1889. |
| --- | --- | --- | --- |
| | Tons of 2000 lbs. | Tons of 2000 lbs. | Tons of 2000 lbs. |
| Pennsylvania | 729,993 | 862,636 | 930,748 |
| Illinois | 321,115 | 299,741 | 245,171 |
| Other States | 333,180 | 265,835 | 244,796 |
| Totals | 1,384,288 | 1,428,212 | 1,420,715 |
| Clapp-Griffiths only | 36,070 | 45,087 | 38,356 |

* *Bulletin of the American Iron and Steel Association*, vol. xxiii. No. 25.

The following table shows the production of Bessemer steel rails of all kinds and sizes in the first half of 1889 compared with the production in each half of 1888, excepting a few thousand tons of Bessemer steel rails which were rolled in iron rolling mills from purchased blooms.

| Rails. | First Half of 1888. | Second Half of 1888. | First Half of 1889. |
|---|---|---|---|
| | Tons of 2000 lbs. | Tons of 2000 lbs. | Tons of 2000 lbs. |
| Pennsylvania . . . . | 420,101 | 491,105 | 523,882 |
| Illinois . . . . . | 256,823 | 231,816 | 179,201 |
| Other States . . . . | 98,337 | 31,650 | 16,489 |
| Totals . . . | 775,261 | 754,571 | 719,572 |

**Imports of Iron Ore, Iron, and Steel.**—The official report of the United States Bureau of Statistics shows that the quantity of iron ore imported during the fiscal year ending June 30, 1889, amounted to 653,206 tons, valued at 1,507,658 dollars, as compared with 919,644 tons in 1887–88, valued at 1,818,034 dollars. The imports of iron and steel were as follows:—

*Value of Iron and Steel Imports.*

| Articles. | 1889. | 1888. |
|---|---|---|
| | Dollars. | Dollars. |
| Pig iron . . . . . . . . . | 2,860,462 | 5,042,886 |
| Scrap iron . . . . . . . . | 394,904 | 1,957,135 |
| Scrap steel . . . . . . . . | 55,432 | 161,014 |
| Bar iron. . . . . . . . . | 1,135,665 | 1,219,461 |
| Iron rails . . . . . . . . | 481 | 5,375 |
| Steel rails . . . . . . . . | 581,109 | 3,219,212 |
| Cotton-ties, iron and steel . . . . | 897,762 | 528,334 |
| Hoop iron . . . . . . . . | 7,314 | 295 |
| Steel hoops, sheets, and plates . . . | 902,456 | 831,941 |
| Steel blooms, billets, and bars . . . | 2,460,390 | 4,442,647 |
| Sheet and plate iron . . . . . | 447,016 | 531,484 |
| Tin plates . . . . . . . . | 21,222,653 | 18,979,344 |
| Wire rods . . . . . . . . | 2,500,394 | 3,648,480 |
| Wire and rope wire . . . . . | 638,554 | 600,988 |
| Anvils, axles, and forgings . . . . | 164,292 | 182,743 |
| Chains . . . . . . . . . | 84,600 | 97,506 |
| Cutlery . . . . . . . . . | 2,362,537 | 2,210,736 |
| Files, rasps, and floats . . . . . | 65,233 | 64,956 |
| Fire-arms . . . . . . . . | 1,159,147 | 1,070,685 |
| Machinery . . . . . . . . | 2,445,379 | 2,079,381 |
| Needles . . . . . . . . . | 288,600 | 316,295 |
| All other . . . . . . . . | 1,708,462 | 1,801,859 |
| Totals . . . . | 42,377,842 | 48,992,757 |

So far as they are stated in the statistical returns, the quantities of iron and steel imported were as follows, in statute tons:—

*Quantities of Iron and Steel Imported into the United States.*

| Articles. | 1889. | 1888. |
|---|---|---|
| | Tons. | Tons. |
| Pig iron | 183,256 | 325,517 |
| Scrap iron | 34,217 | 142,087 |
| Scrap steel | 4,224 | 13,019 |
| Bar iron | 30,884 | 33,153 |
| Iron rails | 20 | 225 |
| Steel rails | 24,257 | 136,799 |
| Cotton-ties | 32,435 | 19,061 |
| Hoop iron | 262 | 9 |
| Steel hoops, sheets, and plates | 20,868 | 22,421 |
| Steel blooms, billets, and bars | 96,264 | 185,397 |
| Sheet and plate iron | 6,885 | 7,215 |
| Tin-plates | 328,454 | 283,457 |
| Wire rods | 80,451 | 120,955 |
| Wire and wire rope | 3,491 | 3,172 |
| Anvils, axles, and forgings | 1,222 | 1,298 |
| Chains | 722 | 922 |
| Totals | 847,912 | 1,294,707 |

The *Iron Age** has compiled from the official reports the following table showing the imports of iron and steel into the United States in the first half of 1889, compared with the first half of 1888:—

| Materials. | Statute Tons. | |
|---|---|---|
| | First Half-year 1889. | First Half-year 1888. |
| Tin-plates | 175,615 | 145,569 |
| Pig iron | 83,279 | 97,260 |
| Steel blooms, &c. | 48,609 | 56,094 |
| Wire rods | 40,110 | 61,472 |
| Scrap iron | 18,818 | 29,390 |
| Bar iron | 11,847 | 12,460 |
| Steel plates, &c. | 8,717 | 11,278 |
| Steel rails | 6,118 | 44,877 |
| Cotton-ties | 4,099 | 2,415 |
| Sheet and plate iron | 3,623 | 2,910 |
| Wire and wire rope | 1,853 | 1,530 |
| Forgings, &c. | 789 | 746 |
| Scrap steel | 730 | 5,685 |
| Chains | 294 | 411 |
| Hoop iron | 6 | (344 lbs.) |
| Iron rails | ... | 1 |
| Totals | 404,507 | 472,098 |
| Iron ore | 391,905 | 326,169 |

* Vol. xliv. p. 247.

**Exports of Iron and Steel.**—The official returns relating to the exports of iron and steel from the United States in the fiscal years ending June 30, 1888 and 1889, are as follows:—

*Value of Iron and Steel Exports from the United States.*

| Articles. | 1889. | 1888. |
|---|---|---|
| | Dollars. | Dollars. |
| Pig iron | 228,945 | 174,414 |
| Band and hoop iron | 1,473 | 4,152 |
| Bar iron | 48,539 | 43,423 |
| Wheels | 74,465 | 108,882 |
| Castings | 369,535 | 264,492 |
| Cutlery | 102,252 | 115,408 |
| Firearms | 820,933 | 593,321 |
| Steel bars | 22,968 | 14,161 |
| Locks and builders' hardware | 1,700,390 | 1,442,635 |
| Machinery | 7,166,748 | 5,519,893 |
| Cut nails | 290,807 | 310,197 |
| Wire nails, including tacks | 157,339 | 155,403 |
| Iron plates and sheets | 28,620 | 198,024 |
| Steel plates and sheets | 2,601 | 6,746 |
| Printing-presses | 223,900 | 186,989 |
| Iron rails | 240 | 2,575 |
| Steel rails | 235,377 | 175,692 |
| Saws and tools | 1,980,878 | 1,659,727 |
| Scales and balances | 301,486 | 325,488 |
| Sewing machines | 2,247,875 | 2,245,110 |
| Fire engines | 10,175 | 1,300 |
| Locomotives | 1,227,149 | 407,014 |
| Stationary engines | 133,473 | 197,040 |
| Boilers | 267,394 | 238,726 |
| Stoves and ranges | 273,261 | 263,730 |
| Wire | 594,616 | 466,355 |
| All other iron and steel | 2,643,213 | 2,642,127 |
| Totals | 21,154,652 | 17,763,034 |

**Condition of the Blast Furnaces.**—At July 1, 1889, there were in blast in the United States 285 blast furnaces out of the total existing number of 544. The weekly capacity of the 285 furnaces in blast was 141,419 tons, and of the 259 which were out of blast, 69,367 tons. The following table shows the condition of the blast furnaces using coke as fuel at the date mentioned: *—

* *Iron Age*, vol. xliv. p. 53.

*Coke Furnaces in the United States.*

| States. | Total Number of Furnaces. | Number in Blast. | Capacity per Week. | Number out of Blast. | Capacity per Week. |
|---|---|---|---|---|---|
| | | | Tons. | | Tons. |
| New York | 3 | 0 | 0 | 3 | 3,377 |
| Pennsylvania: | | | | | |
| Pittsburgh district | 19 | 18 | 21,056 | 1 | 1,462 |
| Spiegeleisen | 1 | 1 | 488 | 0 | 0 |
| Shenango Valley | 19 | 14 | 10,073 | 5 | 2,856 |
| Juniata and Conemaugh Valleys | 17 | 9 | 4,825 | 8 | 2,485 |
| Spiegeleisen | 1 | 1 | 700 | 0 | 0 |
| Youghi. Valley | 5 | 4 | 1,622 | 1 | 730 |
| Miscellaneous | 4 | 3 | 1,686 | 1 | 650 |
| Maryland | 1 | 0 | 0 | 1 | 179 |
| West Virginia | 6 | 3 | 2,418 | 3 | 488 |
| Ohio: | | | | | |
| Mahoning Valley | 14 | 11 | 8,700 | 3 | 1,738 |
| Central and Northern | 16 | 11 | 7,706 | 5 | 3,764 |
| Hocking Valley | 14 | 3 | 1,079 | 11 | 3,563 |
| Hanging Rock | 13 | 6 | 1,720 | 7 | 1,410 |
| Indiana | 2 | 0 | 0 | 2 | 389 |
| Illinois | 12 | 8 | 9,570 | 4 | 2,425 |
| Spiegeleisen | 1 | 1 | 600 | 0 | 0 |
| Wisconsin | 4 | 2 | 1,000 | 2 | 850 |
| Missouri | 6 | 2 | 1,094 | 4 | 2,218 |
| Colorado | 2 | 0 | 0 | 2 | 940 |
| The South: | | | | | |
| Virginia | 12 | 8 | 3,887 | 4 | 1,480 |
| Kentucky | 4 | 2 | 537 | 2 | 630 |
| Alabama | 26 | 21 | 13,278 | 5 | 2,262 |
| Tennessee | 11 | 7 | 3,900 | 4 | 1,200 |
| Georgia | 2 | 1 | 609 | 1 | 310 |
| Totals | 215 | 136 | 96,548 | 79 | 35,406 |

The following tables show the condition of the anthracite and charcoal blast furnaces at July 1:—

*Anthracite Furnaces in the United States.*

| States. | Total Number of Furnaces. | Number in Blast. | Capacity per Week. | Number out of Blast. | Capacity per Week. |
|---|---|---|---|---|---|
| | | | Tons. | | Tons. |
| New York | 23 | 11 | 3,697 | 12 | 3,841 |
| New Jersey | 14 | 4 | 1,867 | 10 | 3,604 |
| Spiegeleisen | 3 | 3 | 218 | 0 | 0 |
| Pennsylvania: | | | | | |
| Lehigh Valley | 46 | 24 | 8,770 | 22 | 7,753 |
| Spiegeleisen | 1 | 1 | 75 | 0 | 0 |
| Schuylkill Valley | 32 | 14 | 4,992 | 18 | 5,231 |
| U. Susquehanna Valley | 17 | 7 | 2,724 | 10 | 1,753 |
| Lebanon Valley | 16 | 15 | 7,573 | 1 | 208 |
| L. Susquehanna Valley | 21 | 10 | 4,226 | 11 | 2,582 |
| Totals | 173 | 89 | 34,142 | 84 | 24,972 |

*Charcoal Furnaces in the United States.*

| States. | Total Number of Furnaces. | Number in Blast. | Capacity per Week. | Number out of Blast. | Capacity per Week. |
|---|---|---|---|---|---|
| | | | Tons. | | Tons. |
| New England | 14 | 8 | 670 | 6 | 420 |
| New York | 10 | 3 | 412 | 7 | 520 |
| Pennsylvania | 23 | 4 | 310 | 19 | 749 |
| Maryland | 8 | 3 | 325 | 5 | 240 |
| Virginia | 23 | 4 | 250 | 19 | 696 |
| West Virginia | 3 | 0 | 0 | 3 | 165 |
| Ohio | 13 | 6 | 324 | 7 | 351 |
| Kentucky | 2 | 2 | 220 | 0 | 0 |
| North Carolina | 2 | 1 | 70 | 1 | 70 |
| Tennessee | 8 | 5 | 1,331 | 3 | 300 |
| Georgia | 2 | 0 | 0 | 2 | 114 |
| Alabama | 9 | 8 | 1,588 | 1 | 210 |
| Michigan | 25 | 9 | 3,091 | 16 | 3,930 |
| Missouri | 3 | 2 | 596 | 1 | 213 |
| Wisconsin | 7 | 2 | 1,011 | 5 | 891 |
| Texas | 1 | 1 | 173 | 0 | 0 |
| California | 1 | 0 | 0 | 1 | 120 |
| Washington | 1 | 1 | 175 | 0 | 0 |
| Oregon | 1 | 1 | 181 | 0 | 0 |
| Totals | 156 | 60 | 10,727 | 96 | 8,989 |

**Iron Industry of New York.**—A review of the iron industry of New York for the past decade is given by Mr. J. C. Smock.* The maximum of production was attained in 1882, after which there was a decline till 1885, and then a rise, with extraordinary outputs, during the last three years.

The iron ores of New York are grouped into seven districts. In the Highlands of the Hudson forty productive mines have been opened. The production of twenty-six mines in 1880 was 184,859 tons, and this decreased to 115,000 tons in 1888. Several mines have ceased to be worked, or are unproductive. The Lake Champion and Adirondack region, with ten idle mines, in 1880 produced 742,865 tons, but since then Chateaugay has been increasingly productive, and also the Port Henry mines. Accordingly, the output amounted to 812,000 tons in 1888. These two districts produce magnetites. The next, St. Lawrence and Jefferson Counties, produce red hæmatites. Three mines have been closed and two fresh ones opened, and the production has risen from 94,765 to 110,000 tons. Clinton and Wayne Counties

* *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 745-750; No 7 *Bulletin of the New York State Museum of Natural History.*

gave 75,000 tons instead of 85,442 tons in 1880; the ores are chiefly fossil hæmatites, and have been mostly worked out in Oneida County. In Dutchess and Columbia Counties, the limonites have mostly been exhausted, and only four mines are in operation, instead of eighteen. At the same time the production has fallen to 43,000 tons from 144,878 tons. The Hudson River carbonates were first put on the market in 1883, and the production is now 350,000 tons. No mines are now in operation on Staten Island.

The total production in 1888 was 1,207,000 tons. Thus New York is fourth on the list of the iron ore producing states. At the commencement of the decade about one hundred mines were at work; last year only fifty were producing ore, but the output for the last three years has been very uniform, which is a proof of their enduring capacity.

**Iron Ore Supply.**—In 1888 the estimated iron ore production of the world was 50,000,000 tons, of which the United States produced one fourth. In addition 587,470 tons were imported, and the amount of mill cinder used in blast furnaces was about 450,000 tons. The total quantity of ore required in the States was about 12,700,000 tons. Mr. J. Birkinbine* reviews the production of the various ore-producing districts of America. The most productive is the Lake Superior region, giving 5,023,279 tons, or 40 per cent. of the total, and the total output up to 1888 has been nearly 41,000,000 tons. The following table shows the work in this district for 1888:—

| Range. | Number of Mines. | Number active during the Year. | Product. | Increase or Decrease over 1887. | Proportion in 1888. |
|---|---|---|---|---|---|
| | | | Statute tons. | Statute tons. | Per cent. |
| Marquette | 74 | 41 | 1,921,525 | 61,482 inc. | 38·3 |
| Menominee | 36 | 22 | 1,165,039 | 34,304 dec. | 23·2 |
| Gogebic | 34 | 21 | 1,424,762 | 139,497 inc. | 28·4 |
| Vermillion | 2 | 2 | 511,953 | 117.701 inc. | 10·1 |

Details are also given of the larger mines in each range. In the whole district there were two mines producing over 400,000 tons, five over 200,000 tons, nine over 100,000 tons, and twelve over 50,000 tons each.

The Cornwall ore banks, during the past decade, have produced 4,421,000 tons, with 722,921 tons in 1888. The Lake Champlain or

* *Transactions of the American Institute of Mining Engineers*, vol. xvii. pp. 715-728.

Adirondack region has produced 15,147,000 tons since the commencement, of which 5,772,000 tons were produced in the past decade, and 789,419 tons in 1888. Bessemer ores are chiefly produced, and many of the lean ores are dressed.

The New Jersey mines show a decrease in production to 447,738 tons from 547,889 tons in 1887, and this is probably due to the competition with seaborne ores. The past decade has shown a production of over five and a half million tons: the total production is estimated at sixteen and a half million tons.

The Missouri district has taken a prominent place, and last year shipped 160,000 tons. There is also a rapid increase in the production of the Southern States, the output being probably about 2,500,000 tons. Of this Alabama contributed about 1,000,000 tons, Tennessee 615,000 tons, and Virginia between 450,000 and 500,000 tons. Ohio produces but little ore, the output in 1888 being 253,352 tons, which is a considerable decrease from the previous year.

Other states produce small amounts of ore. Of these Colorado gave 50,000 tons in 1888. Authentic records of imported ore are only obtainable since 1879, and show an increase from 284,141 tons in that year to a maximum of 1,194,301 tons in 1887, from which point the import fell to 587,470 tons in 1888. The total imports since 1879 have been 6,340,776 tons. Finally, the author arranges the iron ore producing regions in order of production both for 1888 and for the total output, and gives a series of curves which show the comparative yield of the various districts.

**Iron Ore Production of New Jersey.**—In his annual report, Mr. G. H. Cook, the State Geologist of New Jersey, compares the output of iron ore in the state in 1888 with the outputs of previous years. The total output in 1888 was 447,738 tons, a diminution of 100,051 tons as compared with the output of the previous year. The quantities raised in previous years are also given. In 1790 the output was about 10,000 tons, and in 1830 about 20,000 tons. In 1873 it reached 665,000 tons, but diminished again afterwards, until in 1876 it was but 285,000 tons. After this the output again increased, and reached its maximum in 1882, when it amounted to 932,762 tons.

**The Cost of Production of Pig Iron.**—Mr. C. A. Meissner* makes the following estimate of the relative cost of production of pig

* *Iron Age*, vol. xliv. p. 325.

iron in the State of Alabama and in the State of New York, the blast furnace being assumed to be in each case 65 feet high and 14 feet in diameter at the boshes, costing about £20,000 or £25,000 :—

*Cost of Pig Iron per Ton in Alabama.*

| | Dollars. |
|---|---|
| 2 tons of ore at 1.25 dollar | 2.50 |
| 1½ ton of coke at 2.25 dollars | 3.40 |
| 1 ton lime at 65 cents | 0.65 |
| Labour | 1.60 |
| Incidentals | 0.25 |
| Interest, 4 per cent. on total capital | 0.20 |
| Repairs | 0.50 |
| Total | 9.10 |
| Freight to New York | 3.90 |
| Total | 13.00 |
| Selling price at New York | 16.00 |
| Profit per ton | 3.00 |

*Average Cost of Pig Iron per Ton in Ohio and New York.*

| | Dollars. |
|---|---|
| Ore | 5.50 |
| Fuel | 5.00 |
| Lime | 0.80 |
| Labour | 1.75 |
| Incidentals | 0.25 |
| Interest | 0.20 |
| Repairs | 0.50 |
| Total | 14.00 |
| Average freight to New York | 1.00 |
| Total | 15.00 |
| Selling price at New York | 16.00 |
| Profit per ton | 1.00 |

**The Connellsville Coke Industry.**—The following statement relating to the production of coke in the Connellsville district, United States, in 1889, has appeared in the Connellsville *Courier*:—

| Months. | Tons of 2000 lbs. |
|---|---|
| January | 524,447 |
| February | 417,280 |
| March | 443,090 |
| April | 418,534 |
| May | 454,250 |
| June | 421,178 |
| | 2,678,779 |

**Basic Bessemer Process.**—The following table is given by Professor W. B. Phillips * to show the increasing ratio of production of basic Bessemer steel in the world:—

| Description. | 1881. | 1882. | 1883. | 1884. | 1885. | 1886. | 1887. | 1888. |
|---|---|---|---|---|---|---|---|---|
| Acid and basic | 4,533,470 | 5,259,747 | 5,117,092 | 4,802,145 | 5,036,148 | 6,127,991 | 7,349,993 | 6,926,955 |
| Basic . . | 200,000 | 572,604 | 634,373 | 864,000 | 945,317 | 1,313,631 | 1,702,252 | 1,984,484 |
| Acid . . . | 4,333,470 | 4,687,143 | 4,482,719 | 3,938,145 | 4,090,831 | 4,814,360 | 5,647,741 | 4,942,471 |
| Per cent. of ratio | 4·44 | 10·83 | 12·39 | 18·00 | 18·80 | 21·50 | 23·15 | 29·10 |

Since 1878, when the process was started, over 8,000,000 tons of basic Bessemer steel has been produced, and of this total scarcely 50,000 tons has been made in the United States, while now it is not made at all. A suitable pig iron for this process contains carbon 2·5 to 3·0 per cent.; phosphorus, 2·0 to 3·0; sulphur, upper limit, 0·6; silicon, upper limit, 1·5; manganese, 1·0 to 3·0 per cent. This kind of pig iron is not manufactured in the States, and it is difficult to find suitable ore, though investigations are now being made with some hope of success. The most favourable outlook for the process is in the Southern States, especially Alabama.

* *The Engineering and Mining Journal*, vol. xlviii. p. 30.

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| A Treatise on the Metallurgy of Iron, containing Outlines of the History of Iron Manufacture, Methods of Assay and Analyses of Iron Ores, Processes of Manufacture of Iron and Steel, &c. Sixth edition, revised and enlarged. By H. Bauerman, F.G.S. | The Author. |
| Potts' Mining Register and Directory for the Coal and Ironstone Trades of Great Britain and Ireland. 1889. | |
| The Treatment of Steel by Hydraulic Pressure. By W. H. Greenwood, C.E. (Paper read before the Institution of Civil Engineers, May 7, 1889.) | The Author. |
| On the Colours produced during the Tempering of Steel. By Thomas Turner, A.R.S.M. (Read before the Birmingham Philosophical Society on June 13th, 1889.) | The Author. |
| The Economical Firing of Boilers. By W. J. Bird. (Paper read before the South Staffordshire Institute of Iron and Steel Works' Managers.) | The Author. |
| A Short Description of the Process of Manufacturing Iron or Steel by the Robert-Bessemer System in Conjunction with the "Basic" or "Dephosphorising" Process. 1889. | The Robert-Bessemer Process Company. |

| Donations. | By whom Presented. |
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| Chief Engineer's Report of the Engine, Boiler, and Employers' Liability Insurance Company (Limited) for 1888. | The Company. |
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| Report of the National Association for the Promotion of Technical Education. July, 1889. | The Association. |
| Catalogue of books, reports, pamphlets, &c., on technical and secondary education. | Association for the Promotion of Technical Education. |
| The Manufacture of Styrian Open-Hearth Steel, with some Notes on the Treatment of Tool Steel. By F. Korb and Thomas Turner, A.R.S.M. (Paper read before the South Staffordshire Institute of Iron and Steel Works' Managers, on February 2nd, 1889.) | The Authors. |
| Further Notes on Styrian Open-Hearth Steel. By F. Korb and Thomas Turner, A.R.S.M. (Paper read before the South Staffordshire Institute of Iron and Steel Works' Managers.) | The Authors. |
| Annual Report of the Free Library Museum and Science and Art Schools, Cardiff. 1888–89. | The Librarian. |
| Catalogue of Tools and Machinery. Buck & Hickman, 1889. | Messrs. Buck & Hickman. |
| Report on the Cracking of Steel Plates at the Works of Messrs. Day, Summer, & Co., Southampton. October, 1888. By Mr. William Parker of Lloyds. | Mr. Parker. |
| Report of the Committee appointed to Inquire into the Explosion of an Air Receiver at Ryhope Colliery. (Excerpt Minutes of Proceedings of the North of England Institute of Mining and Mechanical Engineers.) | The Institution. |
| Prospectus of the Normal School of Science and Royal School of Mines. Session, 1889–90. | The Secretary. |
| Spon's Engineer's and Contractor's Diary and Reference Book for 1890. | Messrs. E. & F. N. Spon. |
| **AUSTRALASIA.** | |
| Records of the Geological Survey of New South Wales. Parts I. and II. 1889. | The Department of Mines. |
| Memoirs of the Geological Survey of New South Wales. Contributions to the Tertiary Flora of Australia. | The Department of Mines. |

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| Descriptive Catalogue of Exhibits of Metals, Minerals, Fossils, and Timbers at the Melbourne Centennial International Exhibition, 1888. | New South Wales Commission. |
| Annual Report of the Secretary for Mines for the Year 1887. | The Department of Mines. |
| Reports of the Mining Registrars on the Goldfields of Victoria, for the years 1888 and 1889. | The Government of Victoria. |
| Reports on Mining Machinery and Treatment of Ores in Australian Colonies and America. 1889. | The Department of Mines. |
| Report on the Mining Industry of New Zealand. 1889. | The Department of Mines. |

## BELGIUM.

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| Statisque des mines, minières, carrières usines métallurgiques et appareils a vapeur pour l'année 1888. By M. Em. Harzé. | The Author. |

## FRANCE.

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|---|---|
| Papers read before the Congrès international des mines et de la métallurgie at Paris, 1889 :— | M. Bresson. |
| Progrès récents de l'affinage et de la déphosphoration dans la fabrication des fers et aciers. Par M. G. Bresson et par M. E. Gruner. | |
| Nouveaux procédés de trempe. Par M. F. Osmond. | The Author. |
| L'électricité dans les mines. Par M. Chalon. | |
| Description of the Société des Acieres de Longwy. | The Company. |
| Comité des forges de France. L'industrie sidérurgique á l'Exposition Universelle de 1889. | The Comité. |
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| Programm de Congrès International de mécanique appliquée de 1889. | The Secretary. |

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| **GERMANY.** | |
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| Musterbuch für Eisen-constructionen. By C. Scherowsky. Berlin, 1889. | Herr Schrodter. |
| **SWEDEN.** | |
| Underdånig Berättelse anjående Konigl. Patentbyråus Verksamket. Hugo E. G. Hamilton. | |
| Betingelser för äudamålsenlig fromställening af Tackjernsgjutgods samt nya auväudmingar af Kiseljern af Professor Richard Åkerman. | The Author. |
| **ITALY.** | |
| Annali di Agricoltura. 1889. | The Minister of Agriculture. |
| Relazionie sul Servizio Minerario, nel 1887. | The Minister of Agriculture. |
| **INDIA.** | |
| Ceylon Administration Reports for 1888. Part IV. Miscellaneous Railways. | The Government. |
| **UNITED STATES.** | |
| The Chemical Analysis of Iron. By A. A. Blair. | The Author. |
| Report of the Railroad Commissioners of Iowa. 1888. | The Governor of Iowa. |
| Report of the Bureau of Labour Statistics, Conn. 1887. | The Bureau. |
| Notes on the Construction of Ordnance. Vol. II. 1889. | The Chief of Ordnance. |
| Reports of the Consuls of the United States. 1889. | The Bureau. |
| The Use of Metal Track on Railways as a Substitute for Wooden Ties. By E. Russell Tratman. 1888. | Department of Agriculture. |
| Statistics of the American and Foreign Iron Trades for 1888. (Annual Statistical Report of the American Iron and Steel Association.) | Mr. J. M. Swank. |

| Donations. | By whom Presented. |
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| Report of the Testing of Metals and other Materials for Industrial Purposes made with the United States Testing Machine at Watertown Arsenal, Massachusetts, during the year ended June 30, 1886. | The United States War Department. |
| Pig Iron of Unusual Strength. By Fred. P. Dewey. (A Paper read before the American Institute of Mining Engineers.) October, 1888. | The Author. |
| The Theory of Wages. By Stuart Wood. March 1889. | The Author. |
| A New View of the Theory of Wages. By Stuart Wood. | The Author. |
| Birmingham, Alabama, its Resources and Prospects. 1889. | Mr. Andrew Carnegie. |

The "Proceedings" of the Societies, and the technical journals, &c., which follow, have been acquired by exchange:—

## UNITED KINGDOM.—London—

The Royal Society.
The Chemical Society.
The Royal Institution.
The Institution of Civil Engineers.
The Institution of Mechanical Engineers.
The Institution of Naval Architects.
The Institution of Electrical Engineers.
The Royal United Service Institution.
The Royal Artillery Institution.
The Society of Arts.
The Royal Institute of British Architects.
The Society of Chemical Industry.
The Society of Engineers.

## UNITED KINGDOM.—The Provinces—

The Manchester Literary and Philosophical Society.
The Manchester Geological Society.
The Liverpool Polytechnic Society.
The Cleveland Institution of Engineers.
The North-East Coast Institution of Engineers and Shipbuilders.
The Institution of Engineers and Shipbuilders in Scotland.
The South Wales Institute of Mining Engineers.

The North of England Institution of Mining and Mechanical Engineers.
The Royal Dublin Society.
The Bristol Naturalists' Society.
The Mining Institute of Scotland.
The South Staffordshire Institute of Iron and Steel Works Managers.

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"The Engineer."
"Engineering."
"Industries."
"The Ironmonger."
"The Iron and Coal Trades Review."
"Ryland's Iron Trade Circular."
"Iron."
"London Iron Trade Exchange."
"The Economist."
"The Statist."
"British Trade Journal."
"Martineau and Smith's Hardware Trade Journal."
"The Railway Engineer."
"The Contract Journal."
"The Shipping World."
"The Machinery Market."
"The Marine Engineer."
"Mechanical Progress."
"The Electrician."
"The Electrical Engineer."
"Railway News."
"The Mining Journal."
"The Colliery Guardian."
"Practical Engineer."
"Electrical Plant."
"The Steamship."

UNITED STATES—

The American Association for the Advancement of Science.
The American Society of Civil Engineers.
The American Society of Mechanical Engineers.
The American Institute of Mining Engineers.
The Smithsonian Institution.
The American Patent Office.
The United States Geological Survey.
The Franklin Institute.

"The Iron Age."
"The Age of Steel."
"Bradstreets."
"The Engineering and Mining Journal."
"The American Manufacturer."
"Bulletin of the American Iron and Steel Association.
"Railroad Gazette."
"Manufacturers' Record."

## FRANCE—

Société des Ingéniéurs Civils.
Société Scientifique Industrielle de Marseilles.

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"Annales des Mines."
"Bulletin du Ministère des Travaux Publics."
"Comité des Forges de France."
"Le Fer."
"L'Echo des Mines et de la Métallurgie."
"Revue-Gazette Maritime et Commerciale."

## BELGIUM—

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"Moniteur des Intéréts Matériels."
"Bulletin de l'Association des Ingénieurs des Ecole Spécial de Gand."
"L'Union des Charbonnages, Mines, et Usines Métallurgiques de la Province de Liége."
"Bulletin de l'Association des Ingénieurs sortis de l'École de Liége."
"Annuaire de l'Association des Ingénieurs sortis de l'École de Liége."

## GERMANY—

"Stahl und Eisen."
"Glaser's Annalen für Gewerbe und Bauwesen."
"Chemiker-Zeitung."
"Zeitschrift des Vereines Deutscher Ingenieure."
"Zeitschrift für das Berg-, Hütten- und Salinen-wesen im Preussischen Staate."
"Verhandlungen des Vereins zur Beförderung des Gewerbefleisses."

AUSTRIA—

"Oesterreichische Zeitschrift für Berg- und Hüttenwesen."
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ITALY—

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SWEDEN—

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"Ingeniörs Föreningens Förhandlingar."

CANADA—

The Geological Survey.
"The Mining Review."

INDIA—

"The Geological Survey of India."
"The Indian Engineer."
"Indian Engineering."

NEW SOUTH WALES—

"Journal of the Royal Society."

SPAIN—

"Revista Minera y Metallurgica."

NORWAY—

"Norsk Teknisk Tidskrift."

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THE END.

PRINTED BY BALLANTYNE, HANSON AND CO.
EDINBURGH AND LONDON.

THE

# IRON AND STEEL INSTITUTE.

ESTABLISHED 1869.

# LIST OF MEMBERS,

## RULES, &c.

London:
VICTORIA MANSIONS, VICTORIA STREET.
1890.

THE

# IRON AND STEEL INSTITUTE.

# INDEX TO RULES.



APPENDIX.

# THE IRON AND STEEL INSTITUTE.

## RULES.

1. The Society shall be designated "The Iron and Steel Institute."

2. The objects of the Institute shall be—

To afford a means of communication between members of the Iron and Steel Trades upon matters bearing upon their respective manufactures, excluding all questions connected with wages and trade regulations.

To arrange periodical meetings for the purpose of discussing practical and scientific subjects bearing upon the manufacture and working of iron and steel.

### Section I.—**Constitution.**

3. The Institute shall consist of members who shall be more than twenty-one years of age, and shall have one or other of the following qualifications:—

(*a*) Persons practically engaged in works where iron or steel is produced or worked.

(*b*) Persons of scientific attainments in metallurgy, or specially connected with the application of iron and steel.

It shall be within the province of the Council to elect Honorary Members, the number not to exceed twenty.

### Section II.—**Election of Members.**

4. A recommendation for admission according to Form A in the Appendix shall be forwarded to the General Secretary, and by him be laid before the Council. The recommendation shall be in writing, and be signed by not fewer than three members.

5. Such applications for admission as are approved by a majority of the Council shall be inserted on a voting list. This voting list shall specify the name, occupation, address, and proposers of the candidates, and shall be forwarded to the members at least fourteen days previous to the next general meeting, when the lists that have been returned to

the General Secretary shall be opened, only in presence of the members, by Scrutineers, to be appointed by the meeting for that purpose. The elections shall take place at the general meetings only.

[*Note.—Gentlemen whose proposal forms are passed by the Council after the voting lists have been issued, shall be allowed to attend the subsequent general meeting; and if afterwards duly elected members, it is understood that their subscription becomes payable in respect of the year in which said meeting is held.*]

6. The election shall take place by ballot, three-fifths of the votes recorded being necessary for election.

7. When the proposed candidate is elected, the General Secretary shall give him notice thereof, according to Form B, but his name shall not be added to the list of members of the Institute until he shall have paid his first annual subscription, and signed the Form C in the Appendix.

8. In the case of non-election, no mention thereof shall be made in the minutes, nor any notice given to the unsuccessful candidate.

## Section III.—**Officers and Mode of Election.**

9. The officers of the Institute for the management of its affairs shall consist of one President, nine Vice-Presidents, fifteen Members of Council, a Secretary or Secretaries, and one Treasurer. All members who have filled the office of President of the Institute shall be *ex-officio* permanent members of the Council, under the title of Past-Presidents.

10. The President shall be elected for two years, and shall not be eligible for re-election until after an interval; three Vice-Presidents and five Members of the Council, in rotation, shall retire annually, but shall be eligible for re-election, unless disqualified by non-attendance during the previous year. In addition, those Vice-Presidents and Members of Council shall retire who have not attended any meeting of the Council or Institute during the previous year, unless such non-attendance has been caused by special circumstances, which shall have been duly notified to the Council.

11. Candidates shall be put in nomination at the ordinary general meeting preceding the annual meeting, when the Council shall present a list specifying which of the number are eligible for re-election. Any member shall be then entitled to add names to the list of candidates. Members may also nominate candidates for office up to one month previous to the annual meeting, the names to be sent to the General Secretary. The voting list of the proposed names shall be forwarded to the members, and must be returned to the General Secretary previous to the election.

12. Each member may erase any name or names from the lists, but the number of names on the list, after such erasure, must not exceed the number to be elected to the respective offices as before enumerated. The lists which do not accord with these directions shall be rejected by the

Scrutineers. The votes for any member who may not be elected as President or Vice-President shall count for him as Vice-President or other member of the Council. The voting to be conducted in the manner specified in Section II.

13. The Council shall have power to fill up any vacancies that may occur during their year of office.

## Section IV.—Duties of Officers.

14. The President shall be Chairman at all meetings at which he shall be present, and in his absence one of the Vice-Presidents. In the absence of a Vice-President, the members shall elect a Chairman for that meeting.

15. The Treasurer shall hold in trust the uninvested funds of the Institute, which shall be deposited in the name of the Society at a bank approved by the Council; he shall receive all moneys, and shall pay all accounts that are properly certified as correct by the Council; and shall present, from time to time, a statement of the Society's accounts.

16. The General Secretary shall attend all meetings, shall take minutes of the proceedings, shall be responsible for the safe custody of all papers, books, and other property of the Institute, and, under the direction of the Council, shall conduct the general business of the Institute.

## Section V.—Meetings.

17. There shall be at least two general meetings in each year, one of which shall be held in London in the Spring, and the other in August or September, in such locality as the Council may direct. The meeting in the Spring shall be the annual meeting for the election of officers.

18. Twenty members shall be entitled to call, through the General Secretary, a special meeting, the objects thereof to be stated in the requisition. The business of such meeting shall be confined to the special subjects named in the notice convening the same.

19. All members shall have notice of, and shall be entitled to attend, each meeting of the Institute, and to receive copies of the Institute's publications gratuitously.

20. No alteration of the Rules or Bye-laws shall be made except at the annual meeting, and a notice of any proposed alterations shall be given at the general meeting to be held in August or September.

## Section VI.—Subscriptions.

21. The subscription of each member shall be two guineas per annum; and members elected after January 1st, 1870, shall pay an entrance fee of two guineas each.

22. The subscriptions shall be payable in advance on January 1st in each year. Any member whose subscriptions shall be twelve months in

arrear shall forfeit all the privileges of the Institute; and the Council, after having given due notice, in the form D in the Appendix, shall be empowered to remove such name from the lists of the Institute.

### SECTION VII.—Communications of Members.

23. All communications shall be submitted to the Council, and, after their approval, shall be read at the general meetings.

24. All communications made to the Institute shall be the property of the Society, and shall be published only in the Transactions of the Institute, or by the authority of the Council.

### SECTION VIII.—Property of the Institute.

25. All the property of the Institute, other than funds in the hands of the Treasurer, shall be held by three Trustees, in trust for the Society. The Trustees shall be appointed by the members in general meeting assembled; and in case any vacancy in the Trustees occurs, the same shall be filled by election at the next general meeting—the Chairman, in all cases, having a second or casting vote.

26. All books, drawings, communications, models, and the like, shall be accessible to all members according to the Bye-laws. The Council shall have power to deposit the same in such place or places as may be considered most convenient for the members.

27. Every person desirous of bequeathing to the Institute any personal property, is requested to make use of the following form in his will:—"I give and bequeath to the Trustees of the Iron and Steel Institute in London [here mention the property or sum of money intended to be bequeathed] for the use of the Institute."

### SECTION IX.—Consulting Officers.

28. The members in general meeting assembled shall have power to appoint such consulting officers as may be thought desirable from time to time, and may vote them suitable remuneration.

### SECTION X.—Prizes.

29. The Society may offer annually a certain sum to be appropriated in Prizes or Medals, for Essays on subjects prescribed by the Council, for inventions of a specified character, or for improvements in special departments of the iron or steel manufactures. A list of the subjects for which prizes will be given shall be presented in each Annual Report.

### SECTION XI.—Dissolution.

30. The Institute shall not be broken up unless upon the vote of two-thirds of the members present at any general meeting, convened for the

purpose of considering the dissolution; and after confirmation by a similar vote, at a subsequent meeting, to be held not less than three, or more than six months after the first; and notice of this last meeting shall be duly advertised as the Council or a general meeting may advise.

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# APPENDIX.

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## FORM A.

Mr. A. B. (address in full), being of the required age, and desirous of becoming a member of the Iron and Steel Institute, we, the undersigned, from our personal knowledge, do hereby recommend him for election.

His qualifications are ______________________

______________________

Witness our hands this ______ day of ________ 18

______________ }
______________ } *Names of Three Members.*
______________ }

## FORM B.

Sir,—I beg to inform you that on the ____________ you were elected a member of the Iron and Steel Institute, but, in conformity with the Rules, your election cannot be confirmed until the accompanying form be returned with your signature, and until your entrance fee and first annual subscription (amount £________) be paid to me. If the first subscription is not received within two months of this date, your election will become void.

I am, Sir, your obedient Servant,

______________, *General Secretary.*

______ day of ________ 18

## FORM C.

I, the undersigned, being elected a member of the Iron and Steel Institute, do hereby agree that I will be governed by the regulations of the said Institute, as they are now formed, or as they may be hereafter altered; that I will advance the interests of the Institute as far as may be in my power; provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing my name therefrom, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand this___________day of ___________18

## FORM D.

SIR,—I am directed to inform you that your subscription to the Iron and Steel Institute, amounting to ________, is in arrear, and that if the same be not paid to me on or before the____________day of__________ 18_____, your name will be removed from the lists of the Institute.

I am, Sir, your obedient Servant,

_______________, *General Secretary.*

# LIST OF MEMBERS.

*CORRECTED TO DECEMBER 31st, 1889.*

## HONORARY MEMBERS.

**ÅKERMAN, Professor R., Bergsskolan, Stockholm.**
**BELGIANS, H.M. LEOPOLD II., KING OF THE, Brussels.**
**HEWITT, Hon. ABRAM S., New York, U.S.A.**
**TUNNER, PETER RITTER VON, Leoben, Austria.**
**WALES, H.R.H. ALBERT EDWARD, PRINCE OF, K.G., K.T., K.P., G.C.B., G.C.S.I., &c., Marlborough House, Pall Mall, S.W.**

## ORDINARY MEMBERS.

*Those Marked * are Original Members.*

| Elected Member | |
|---|---|
| 1878 | Abel, Sir Fredk. Augustus, C.B., F.R.S., *Royal Arsenal, Woolwich, S.E.* |
| 1870 | Adams, George, *Priestfields, near Wolverhampton.* |
| 1869 | *Adamson, Daniel, *The Towers, Didsbury, near Manchester.* |
| 1872 | *Addie, James, *Langloan Iron Works, Coatbridge, N.B.* |
| 1869 | *Addie, John, *Langloan Iron Works, Coatbridge, N.B.* |
| 1889 | Adler, Harmer, *Chicago, U.S.A.* |
| 1880 | Addyman, Thos., *West Gorton, Manchester.* |
| 1888 | Ainslie, Frank, *S. Lindal Moor Mines, Ulverston.* |
| 1869 | *Ainslie, W. G., M.P., *23 Abingdon Street, London, S.W.* |
| 1872 | Ainsworth, George, *Consett Iron Works, Consett, County Durham.* |
| 1887 | Aird, John, 37 Great George Street, London, S.W. |

| Elected Member | |
|---|---|
| 1869 | *Aitken, Henry, *Almond Iron Works, Falkirk, N.B.* |
| 1881 | Akrill, Charles, *Golds' Green Foundry, West Bromwich.* |
| 1875 | Albright, A., *Mariemont, Birmingham.* |
| 1880 | Alger, Charles, *Hudson, New York, U.S.A.* |
| 1887 | Allan, George, *Corngreaves Works, Birmingham.* |
| 1883 | Allan, T. A., *The Tharsis Mines, Huelva, Spain.* |
| 1875 | Allen, Alfred H., 1 *Surrey Street, Sheffield.* |
| 1880 | Allen, H., *Endcliffe, Sheffield.* |
| 1872 | Allen, William Daniel, *Bessemer Steel Works, Sheffield.* |
| 1880 | Allen, W. Edgar, *Imperial Steel Works, Saville Street, Sheffield.* |
| 1869 | *Alleyne, Sir John G. N., Bart., *Cevin, Belper.* |
| 1886 | Alley, Stephen, *Sentinel Works, Glasgow.* |
| 1875 | Alleyne, Reynold Henry Newton, *Leeds Old Foundry, March Lane, Leeds.* |
| 1879 | Allison, Hy. Thos., *Grosmont Iron Works, Grosmont, by York.* |
| 1874 | Allport, Charles J., 11 *Euston Square, London, N.W.* |
| 1871 | Allport, Howard Aston, *Dodworth Grove, Barnsley.* |
| 1889 | Anderson, Alexander, 12 *Wellington Road, Old Charlton, S.E.* |
| 1880 | Anderson, C., 3 *Belmont Grove, Leeds.* |
| 1874 | Anderson, Samuel, *Westbury Iron Works, Wiltshire.* |
| 1875 | Anderson, William, *Lesney House, Erith, Kent.* |
| 1883 | Anderson, W., *Stockton-on-Tees.* |
| 1885 | Andrew, Hy. Herbert, *Ranmoor, Sheffield.* |
| 1880 | Andrew, J. A., *Toledo Steel Works, Sheffield.* |
| 1873 | Angus, Robert, *Lugar Iron Works, Cumnock, Ayrshire.* |

| Elected Member | |
|---|---|
| 1880 | Annable, W., *Woodwill, Grimes Thorpe, Sheffield.* |
| 1875 | Anstice, R. E., *Madeley Wood, Iron Bridge, Salop.* |
| 1869 | *Armstrong, Lord, C.B., *Elswick Iron Works, Newcastle-on-Tyne.* |
| 1885 | Arrol, James C., 18 *Blythswood Square, Glasgow.* |
| 1885 | Arrol, Thomas A., *Germiston Iron Works, Glasgow.* |
| 1883 | Ascherson, E., 20 *Abchurch Lane, Cannon Street, E.C.* |
| 1875 | Ashbury, Thomas, *Ash Grove, Victoria Park, Longsight, Manchester.* |
| 1887 | Aspinall, Jno. A. F., *Fernbank, Heaton, Bolton-le-Moors.* |
| 1883 | Asthower, Frederick, *Ammen, Westphalia.* |
| 1880 | Atkinson, A. J., 44 *London Square, Bute Street, Cardiff.* |
| 1889 | Atkinson, Edward T., 24 *Erlanger Road, New Cross, S.E.* |
| 1879 | Atkinson, M. H., 21 *Windsor Terrace, Newcastle-on-Tyne.* |
| 1882 | Austin, Kenneth S., *Washwood Heath Road, Birmingham.* |
| | |
| 1881 | Baare, Fritz, *Bochum, Westphalia.* |
| 1873 | Bagley, Charles Jno., *Moor Iron Works, Stockton-on-Tees.* |
| 1872 | Bagnall, Thomas, *Grosmont Iron Works, viâ York.* |
| 1877 | Bagshawe, Washington, *Monkbridge Iron Works, Leeds.* |
| 1887 | Bailey, William H., *Salford, Manchester.* |
| 1873 | Bain, Sir James 3 *Park Terrace, Glasgow.* |
| 1874 | Bain, J. R., *Harrington Iron Works, Harrington, Cumberland.* |
| 1880 | Baird, Geo., *Fulmer, Slough.* |
| 1869 | *Baldwin, Alfred, *Wilden, near Stourport.* |
| 1885 | Bamforth, Thos., *Carron Works, Falkirk, N.B.* |

| Elected Member | |
|---|---|
| 1877 | Bamlett, A. C.,<br>*Thirsk, Yorkshire.* |
| 1880 | Banister, F. Dale,<br>*Stonehouse, Forest Row, Sussex.* |
| 1889 | Banister, Herbert,<br>*London Bridge Station, London Bridge.* |
| 1869 | *Bantock, Thomas,<br>*Merridale House, Wolverhampton.* |
| 1879 | Barba, Joseph,<br>*Creusot, France.* |
| 1879 | Barber, James Hy.,<br>*Sheffield Iron and Steel Works, Attercliffe, Sheffield.* |
| 1880 | Barbour, Thos.,<br>*Derwent Hematite Iron Works, Workington.* |
| 1876 | Bargate, George,<br>*Barrow-in-Furness.* |
| 1869 | *Barker, George J.,<br>*Albrighton Hall, Wolverhampton.* |
| 1886 | Barlow-Massicks, Horace,<br>*Askam Iron Works, Askam-in-Furness.* |
| 1869 | *Barlow-Massicks, Thomas,<br>*The Oaks, Millom, Cumberland.* |
| 1879 | Barnaby, Sir Nathaniel, K.C.B.,<br>*Lee, Kent.* |
| 1883 | Barnett, F. T.,<br>*Bury Street, Salford.* |
| 1889 | Barningham, Robert B.,<br>*Saxenholme, Upper Chorlton Road, Manchester.* |
| 1873 | Barningham, Thomas,<br>*Corporation Street, Manchester.* |
| 1889 | Barns, George T.,<br>*Crane Iron Company, Philadelphia, U.S.A.* |
| 1882 | Barrett, W. Henry,<br>*Care of M. Martinez de las Rivas, Bilboa, Spain.* |
| 1880 | Barrow, James,<br>*Maesteg, Glamorganshire.* |
| 1885 | Bartlett, Jas. H.,<br>*Standard Building, Montreal, Canada.* |
| 1887 | Barton, Albert Edward,<br>*Eureka Furnaces, Oxmoor, Jefferson Co., Alabama, U.S.A.* |
| 1869 | *Barton, Edward,<br>*Carnforth Hematite Iron Works, Carnforth.* |
| 1881 | Bayard, Paul,<br>*Forges de Montataire, Montataire, France.* |
| 1883 | Bayles, J. C.,<br>83 *Reade Street, New York, U.S.A.* |
| 1873 | Bayley, Jno. Clowes,<br>1 *Queen Victoria Street, London, E.C.* |

| Elected Member | |
|---|---|
| 1881 | Bayliss, Moses,<br>*St. Cuthbert's, West Heath Road, Hampstead, N.W.* |
| 1881 | Bear, T. Drew,<br>*113 Queen Victoria Street, London, E.C.* |
| 1880 | Beard, A.,<br>*5 Exchange Buildings, Swansea.* |
| 1886 | Beard, George,<br>*Gartcosh, Glasgow.* |
| 1882 | Beardmore, Isaac,<br>*Parkhead Iron and Steel Works, Glasgow.* |
| 1878 | Beardmore, William,<br>*Parkhead Rolling Mills, Glasgow.* |
| 1889 | Beardshaw, Wm. Fredk.,<br>*Baltic Steel Works, Sheffield.* |
| 1884 | Beaulieu, Henri,<br>*Pagny-sur-Meuse, France.* |
| 1884 | Beck-Guerhard, V. N.,<br>*Nevsky 110, St. Petersburgh.* |
| 1881 | Beckett, J. S.,<br>*Brooklyn Works, Sheffield.* |
| 1882 | Beckwith, Jno. H.,<br>*Knott Mill Iron Works, Manchester.* |
| 1889 | Bedford, Joseph,<br>*Sunny Bank, Sheffield.* |
| 1874 | Bedson, Joseph P.,<br>*Bradford Iron Works, Manchester.* |
| 1886 | Bell, Charles,<br>*21 Victoria Place, Stirling.* |
| 1876 | Bell, Charles Lowthian,<br>*Middlesbrough.* |
| 1883 | Bell, H. S.,<br>*6 Dents Road, Wandsworth Common, London, S.W.* |
| 1869 | *Bell, Sir Lowthian, Bart., F.R.S.,<br>*Rounton Grange, Northallerton.* |
| 1889 | Bell, Robert,<br>*Clifton Hall, Ratho, Edinburgh.* |
| 1869 | *Bell, Thomas,<br>*Oakwood, Epping.* |
| 1869 | *Bell, T. Hugh,<br>*Clarence Iron Works, Middlesbrough.* |
| 1886 | Bell, Charles Ernest,<br>*Park House, Durham.* |
| 1889 | Bellhouse, Ernest,<br>*Eagle Quay, Manchester.* |
| 1888 | Bennett, James,<br>*12 Hamilton Drive, Glasgow.* |
| 1881 | Benson, R. Seymour,<br>*Hope Iron Works, Stockton-on-Tees.* |

| Elected Member | |
|---|---|
| 1873 | Bergen, A. Von., *Cleveland Terrace, Darlington.* |
| 1883 | Bergendal, F. J., *Horndal, Sweden.* |
| 1869 | *Bessemer, Sir Henry, F.R.S., *Denmark Hill, London, S.E.* |
| 1886 | Biles, John Harvard, *Clydebank, Glasgow.* |
| 1875 | Birch, George 3 *Brentwood, Pendleton, Manchester.* |
| 1873 | Bishop, Frederick S., *Glaurafon, Sketty, Swansea.* |
| 1887 | Black, Thomas, *Tudhoe Iron Works, Spennymoor, County Durham.* |
| 1885 | Blair, George Maclellan, *Clutha Iron Works, Glasgow.* |
| 1885 | Blair, James Maclellan, *Clutha Iron Works, Glasgow.* |
| 1875 | Blair, Thomas, *c/o Joseph Bedford, Haymarket Chambers, Sheffield.* |
| 1878 | Blake, Thomas, *Stockton-on-Tees.* |
| 1879 | Blakemore, Wm., 81 *Newport Road, Cardiff, Glamorganshire.* |
| 1881 | Bleckly, C. A., 61 *King William Street, London, E.C.* |
| 1878 | Bleckly, Herbert Sanderson, *Altrincham, Cheshire.* |
| 1869 | *Bleckly, John James, *Warrington.* |
| 1869 | *Bleckly, W. H., *Thelwall Lea, near Warrington.* |
| 1889 | Bleichert, Adolf, *Leipzig-gohlis, Germany.* |
| 1882 | Böcking, Edw., *Mulheim-on-Rhine, Germany.* |
| 1869 | *Bodmer, J. J., *Dashwood House, New Broad Street, London, E.C.* |
| 1869 | *Bolckow, C. F. H., *Marton Hall, Middlesbrough.* |
| 1880 | Bollinger, Henry, *Milan, Italy.* |
| 1884 | Bond, F. W., *Margrave Hill, Henley-on-Thames.* |
| 1888 | Bond, George, *Newcastle Chambers, Nottingham.* |
| 1883 | Borbeley, Ludwig, *Salgo-Tarjan, Hungary.* |

| Elected Member | |
|---|---|
| 1887 | Bott, Joseph Elton,<br>*Manchester Steel Castings Company, Openshaw, Manches* |
| 1882 | Bowman, Harold,<br>*Knott Mill Iron Works, Manchester.* |
| 1873 | Bowser, Howard,<br>13 *Royal Crescent, Glasgow.* |
| 1888 | Boyd, A. C.,<br>*Lakes, Dukinfield, Manchester.* |
| 1889 | Braby, Cyrus,<br>110 *Cannon Street, E.C.* |
| 1874 | Braby, Frederick,<br>*Bushey Lodge, Teddington.* |
| 1887 | Bradley, Bernard Grove,<br>*Parkfield House, Dudley Road, Wolverhampton.* |
| 1888 | Bradley, Wm. Henry,<br>*The Oaklands, Handsworth, Birmingham.* |
| 1886 | Bramall, Charles,<br>*Worrall, near Oughtibridge, Sheffield.* |
| 1882 | Bramwell, Sir F. J., Bart.,<br>5 *Great George Street, Westminster, S.W.* |
| 1888 | Brassey, Lord,<br>24 *Park Lane, London, W.* |
| 1879 | Brauns, Hermann,<br>*Union Works, Dortmund, Germany.* |
| 1885 | Breckon, J. R.,<br>41 *Fawcett Street, Sunderland.* |
| 1887 | Breda, V. S.,<br>*Terni, near Rome.* |
| 1889 | Bremme, Friedrich G. T.,<br>*Julienhütte, bei Bobrek Ober-Schlesien, Germany.* |
| 1888 | Bright, Alfred Charles,<br>*Hawkwell Tin Plate Works, Cinderford.* |
| 1880 | Brock, A.,<br>110 *Cannon Street, London, E.C.* |
| 1872 | Brockbank, William,<br>*Brockhurst, Didsbury, near Manchester.* |
| 1885 | Brodie, Thos. Dawson,<br>5 *Thistle Street, Edinburgh.* |
| 1869 | *Brogden, Henry,<br>*Hale Lodge, Altrincham, Manchester.* |
| 1869 | *Brogden, James,<br>*Sea Bank House, Porthcawl, near Bridgend.* |
| 1885 | Bromilow, John,<br>9 *Bellevue Terrace, Gateshead-on-Tyne.* |
| 1881 | Brooke, Edward,<br>*Edgerton, Huddersfield.* |
| 1888 | Brooke, Edward Burkill,<br>*The Hagg, Wadsley Bridge.* |

| Elected Member | |
|---|---|
| 1883 | Brooks, J. E.,<br>*Clyde Iron Works, Tolcross, Glasgow.* |
| 1877 | Brotherhood, Peter,<br>*Belvedere Road, Lambeth, London, S.E.* |
| 1874 | Brown, Joseph C.,<br>*Hazel Holm, Cleator,* viâ *Carnforth.* |
| 1872 | Brown, Richard,<br>*Haylee, Largs, N.B.* |
| 1873 | Brown, Thomas Forster,<br>*Cardiff.* |
| 1886 | Browne, Frederick John,<br>*Tay Criggan, Ealing Dean, W.* |
| 1889 | Browne, John,<br>*Portugalete, Spain.* |
| 1881 | Brownhill, Wm., Jun.,<br>*Bloxwich Iron and Steel Company, Limited, Walsall.* |
| 1886 | Brownhill, John Justice,<br>*Green Lane Foundry, Walsall.* |
| 1883 | Brown-Westhead, G.,<br>*Gouldon House, Shelton, Stoke-on-Trent.* |
| 1880 | Bruce, John,<br>13 *Ainslie Place, Edinburgh.* |
| 1884 | Brundreth, Alex.,<br>*Rhymney Iron Works, Rhymney.* |
| 1872 | Brunlees, Sir James,<br>5 *Victoria Street, Westminster, S.W* |
| 1880 | Brustlein, H. A.,<br>*Aciéries d'Unieux, Loire, France.* |
| 1876 | Buchanan, A.,<br>*Handyside & Co. (Limited), Derby.* |
| 1888 | Buckley, James,<br>*Brynairan, Llanelly.* |
| 1887 | Buckley, Samuel,<br>*Fern Bank, Oldham.* |
| 1881 | Buckton, Walter,<br>27 *Ladbroke Square, Notting Hill, W.* |
| 1888 | Budd, Edward Fraser,<br>*Brierley Hill, Staffordshire.* |
| 1872 | Bull, James,<br>*Kingsland, Newcastle-under-Lyne.* |
| 1872 | Bullivant, W. M.,<br>72 *Mark Lane, London, E.C.* |
| 1886 | Bullock, Cyrus,<br>67 *King Street, Manchester* |
| 1888 | Bullock, Joseph H.,<br>*Pelsall Iron Works, Walsall.* |
| 1884 | Bunning, Charles Z.,<br>3 *Richmond Hill, Norwich* |

| Elected Member | |
|---|---|
| 1882 | Bunten, James C.,<br>*Anderston Foundry, Glasgow.* |
| 1883 | Bunting, C. V.,<br>*Oldwheel Steel Works, Loxley, near Sheffield.* |
| 1870 | Burden, James A.,<br>*Troy, New York, U.S.A.* |
| 1881 | Burn, R. Scott,<br>*Oak Lea, Edgeley Road, near Stockport.* |
| 1873 | Burns-Lindow, J. L.,<br>*Whitehaven.* |
| 1875 | Burnup, J. Morison,<br>*National Conservative Club, Pall Mall, London, S.W.* |
| 1883 | Burnyeat, William,<br>*Millgrove, Whitehaven.* |
| 1876 | Burridge, Stephen, junr.,<br>*Shirle Hill, Sheffield.* |
| 1881 | Burrows, Ernest J.<br>*Woodlands, Wigan, Lancashire.* |
| 1880 | Bush, George,<br>*Rutland House, Lee Park, S.E.* |
| 1883 | Bush, Dudley, J. C.,<br>*Fort House, South Molton, North Devon.* |
| 1883 | Butler, B. F.,<br>*Kirkstall Forge, Leeds.* |
| 1872 | Butler, Edmund,<br>*Kirkstall Forge, Leeds.* |
| 1876 | Butler, Isaac,<br>*Panteg House, near Newport, Monmouthshire.* |
| 1874 | Butler, Jacob,<br>*Fairfield House, Crockelty Road, Handsworth, Birmingh* |
| 1889 | Butler, Theobald Fitzwalter,<br>*Bayvian, by Ulverston.* |
| 1883 | Butlin, William,<br>*Duston House, near Northampton.* |
| 1882 | Butlin, William Henry,<br>*Irthlingborough Iron Works, Wellingborough.* |
| 1889 | Byers, William Lumsden,<br>*Stroud Iron Works, Sunderland.* |
| 1888 | Byles, Arthur R.,<br>*Hopewell House, Shipley, Yorkshire.* |
| 1874 | Byrne, Samuel Henry,<br>*The Farre Close, Brighouse, Yorkshire* |
| 1877 | Campbell, Daniel,<br>*Harbridge, Catford Hill, S.E.* |
| 1869 | *Carbutt, E. Hamer,<br>19 *Hyde Park Gardens, W.* |

| Elected Member | |
|---|---|
| 1878 | Carmont, William Haselwood,<br>*Mansfield Chambers, St. Ann's Square, Manchester.* |
| 1879 | Carnegie, A.,<br>23 *Broad Street, New York, U.S.A.* |
| 1883 | Carr, Edward,<br>59 *Sinclair Road, West Kensington Park, W.* |
| 1871 | Carrington, Arthur,<br>*Wingerworth Iron Works, Chesterfield.* |
| 1881 | Carruthers, Ben.,<br>*Worsbro' Park, Barnsley.* |
| 1880 | Carson, W.,<br>*Wallasey, Birkenhead.* |
| 1888 | Carter, William Allan,<br>5 *St. Andrew Square, Edinburgh.* |
| 1872 | Cassels, Jno. R.,<br>*Glasgow Iron Works, Glasgow.* |
| 1871 | Cassels, Robert,<br>168 *St. Vincent Street, Glasgow.* |
| 1877 | Casson, Richard Smith,<br>*Round Oak Iron Works, Brierley Hill.* |
| 1882 | Cavendish, Lord Edward, M.P.,<br>*Holker Hall, Grange, Lancashire.* |
| 1886 | Cawley, George.<br>358 *Strand, W.C.* |
| 1889 | Chadwick, David,<br>36 *Coleman Street, London, E.C.* |
| 1876 | Chambers, A. M.,<br>*Thorncliffe Iron Works, Sheffield.* |
| 1872 | Chanove, Gabriel,<br>*Rue de la Thaina* 11, *Paris.* |
| 1872 | Chapman, Henry,<br>113 *Victoria St., Westminster, S.W., and* 10 *Rue Laffitte, Paris.* |
| 1882 | Chapman, John G.,<br>*Tower Hill, Middleton-One-Row, Darlington.* |
| 1884 | Charlton, Hy.,<br>*Gateshead Iron Works, Gateshead.* |
| 1885 | Charlton, Wm.,<br>*Guisbrough, Yorkshire.* |
| 1877 | Chatwood, Samuel,<br>*Dronknaler Park, Prestwick, Lancashire.* |
| 1872 | Cheesman, Wm. T.,<br>*Hartlepool.* |
| 1883 | Cherrie, J. M.,<br>21 *Hope Street, Glasgow.* |
| 1882 | Church, Richard F., M.I.C.E.,<br>1 *Victoria Street, Westminster.* |
| 1888 | Clapp, Geo. H.,<br>95 *Fifth Avenue, Pittsburgh, U.S.A.* |

| Elected Member | |
|---|---|
| 1886 | Claughton, Gilbert H.,<br>*Dudley.* |
| 1874 | Cleghorn, John,<br>*Union Bank Chambers, Spring Gardens, London, S.W.* |
| 1882 | Cleminson, Jas.,<br>*Dashwood House, London, E.C.* |
| 1888 | Clerke, Wm.,<br>*Messrs. Grindlay & Co., Parliament Street, S.W.* |
| 1869 | *Cliff, Joseph,<br>*Frodingham Iron Works, near Doncaster, Lincolnshire.* |
| 1882 | Cliff, Wm. D.,<br>*Wortley, Leeds.* |
| 1875 | Clive, Robert,<br>*Clanway Colliery and Iron Works, Tunstall, Staffordshire.* |
| 1879 | Cochrane, Alfred O.,<br>*Coatham, Redcar.* |
| 1869 | *Cochrane, Charles,<br>*Green Royde, Pedmore, near Stourbridge.* |
| 1883 | Coghlan, C.,<br>*Hunslet Forge, Leeds.* |
| 1887 | Coghlan, John H.,<br>*Grosvenor House, Headingley, Leeds.* |
| 1884 | Cole, Albert,<br>*Brierley House, Brierley Hill.* |
| 1888 | Cole, John Wm.,<br>*c/o Jas. Martin & Co., Phœnix Foundry, Gawler, Sout Australia.* |
| 1883 | Colley, Alfred,<br>*Sheffield Steel and Iron Works, Sheffield.* |
| 1883 | Collonette, R.,<br>*Cocken Villa, Walney Road, Barrow-in-Furness.* |
| 1870 | Colquhoun, James,<br>*Tredegar Iron Works, Tredegar, Monmouthshire.* |
| 1881 | Colquhoun, James, Jun.,<br>*Stanton Iron Works, near Nottingham.* |
| 1877 | Colver, R.,<br>*Continental Steel Works, Sheffield.* |
| 1883 | Colville, D., Jun.,<br>*Motherwell, N.B.* |
| 1880 | Colville, John,<br>*Motherwell, N.B.* |
| 1886 | Cook, Joseph,<br>*Codnor Park, Alfreton.* |
| 1879 | Cook, Joseph, Jun.,<br>*Washington, County Durham.* |
| 1874 | Cooper, Arthur,<br>*North Eastern Steel Works, Middlesbrough.* |

| Elected Member | |
|---|---|
| 1887 | Cooper, Edward, *17 Burling Slip, New York, U.S.A.* |
| 1882 | Cooper, Joseph, *The Laurels, Hill Top, West Bromwich.* |
| 1880 | Cooper, Leonard, *Park Row, Leeds.* |
| 1873 | Copeland, Charles J., *Barrow-in-Furness.* |
| 1879 | Copestake, Sampson, *1 Adelaide Crescent, Brighton.* |
| 1887 | Coppée, Evence, *Engineer, Brussels.* |
| 1880 | Corner, John, *18 Albert Road, Regent's Park, London, N.W.* |
| 1879 | Cornish, Henry John, *2 White Lion Court, Cornhill, E.C.* |
| 1876 | Coventry, J., *34 Linnet Lane, Sefton Park, Liverpool.* |
| 1878 | Cowan, Alex. Bertram, *Tudhoe Iron Works, Spennymoor.* |
| 1883 | Cowan, D., *Carron, Falkirk, N.B.* |
| 1874 | Coward, Edward, *Heaton Mersey, Manchester.* |
| 1870 | Cowper, Charles Edward, *6 Great George Street, Westminster, S.W.* |
| 1869 | *Cowper, E. A., *6 Great George Street, Westminster, S.W.* |
| 1885 | Cowper, James, *St. Rollox Chemical Works, Glasgow.* |
| 1886 | Cowper, Sinclair, *6 Clayton Terrace, Dennistown, Glasgow.* |
| 1886 | Craggs, Henry Foxton, *The Poplars, Middlesbrough.* |
| 1887 | Craven, John, *Osborne Street, Manchester.* |
| 1880 | Craven, T. F., *Craven Bros. & Co., Darnall, Sheffield.* |
| 1884 | Craven, Joseph, *424 Glossop Road, Sheffield.* |
| 1883 | Crawford, A., *Bestwood Coal and Iron Works, near Nottingham.* |
| 1878 | Crawhall-Wilson, T. W., *Alston House, Alston, Cumberland.* |
| 1888 | Crawshay, Tudor, *Bonvilstone, Cardiff.* |
| 1869 | *Crawshay, W. T., *Cyfarthfa Castle, Merthyr Tydvil.* |

| Elected Member | |
|---|---|
| 1886 | Cremer, John Henry, *122 Water Street, Cleveland, O., U.S.A.* |
| 1876 | Crippin, Edwd. Frederick, *Brynn Hall Collieries, near Wigan.* |
| 1880 | Croasdell, S., *Spring Bank, North Side, Workington.* |
| 1869 | *Crompton, George, *Stanton Iron Works, Nottingham.* |
| 1877 | Crompton, R. E. B., *4 Mansion House Buildings, London, E.C.* |
| 1883 | Crooke, Walter, *Duddon Villa, Millom, Cumberland.* |
| 1880 | Crookston, A. W., *19 Wellington Street, Glasgow.* |
| 1886 | Crosland, J. F. Lovelock, *67 King Street, Manchester.* |
| 1883 | Crossley, W. J. *Glenfield, Bowden, Cheshire.* |
| 1869 | *Crossley, William, *153 Queen Street, Glasgow.* |
| 1875 | Crowther, Clement, *Stour Vale Iron Works, Kidderminster.* |
| 1881 | Crum, John, *Workington, Cumberland.* |
| 1885 | Cubillo, Major Leandro, *Ordnance Works, Trubia, Spain.* |
| 1885 | Cumberland, John S., *Weardale Iron and Coal Company, Ld., George Yar Upper Thames Street, E.C.* |
| 1869 | *Cuninghame, John, *127 St. Vincent Street, Glasgow.* |
| 1876 | Cuninghame, J. C., *Craigends, Johnstone, N.B.* |
| 1884 | Cuninghame, A., *Carnbroe Iron Works, Coatbridge, N.B.* |
| 1885 | Cuninghame, Wm., *Belmont, Ayr, N.B.* |
| 1876 | Cunliffe, Richard, *Broughton Iron Works, Manchester.* |
| 1888 | Cunningham, Peter Nisbet, *Blochairn Steel Works, Glasgow.* |
| 1882 | Daelen, R. M., *Kurfürstenstrasse, Düsseldorf, Germany.* |
| 1869 | *Dale, David, *West Lodge, Darlington.* |

| Elected Member | |
|---|---|
| 1881 | Dalgliesh, Richard, *The Limes, Asfordley, Melton Mowbray.* |
| 1886 | Dalton, George, *The Yews, Headingley, Leeds.* |
| 1874 | D'Andrimont, Julien, *Liége, Belgium.* |
| 1887 | Daniel, Edward Rice, *Cwmgelly, Swansea.* |
| 1889 | Danielsson, Carl L., *Bofors Steel Works, Brukdisponent, Sweden.* |
| 1882 | Danks, Samuel J., *Hadley Park, near Wellington, Salop.* |
| 1880 | Darby, J. H., *Brymbo Iron Works, near Wrexham.* |
| 1873 | Darling, Wm. L., *Pewhill, Chippenham.* |
| 1889 | Davenport, Russell W., *Bethlehem, Pa., U.S.A.* |
| 1870 | Davey, George H., *Baglan, near Neath, Glamorganshire.* |
| 1880 | Davey, Henry, 3 *Princes Street, Westminster, London, S.W.* |
| 1884 | Davie, Thomas, *Waverley Iron and Steel Works, Coatbridge, N.B.* |
| 1874 | Davies, Geo. William, *Hawbush Cottage, Stourbridge.* |
| 1889 | Davies, Jasper Gustavus Silvester, *Messrs. Bolckow, Vaughan & Co., Middlesbrough.* |
| 1882 | Davies, John B., *Bilbao, Spain.* |
| 1889 | Davies, William, *Atlas Works, Sheffield.* |
| 1882 | Davies, William H., *Glansychan, Abersychan, near Pontypool, Monmouthshire.* |
| 1875 | Davis, Alfred, 2 *St. Ermin's Mansions, Westminster, London, S.W.* |
| 1878 | Davis, E. Prosser, *Awsworth Iron Works, Ilkeston, near Nottingham.* |
| 1889 | Davis, J. H., 1 *Arthur Street West, King William Street, E.C.* |
| 1883 | Davy, Abraham, *The Oaks, Pitsmoor, Sheffield.* |
| 1889 | Davy, Charles, *Park Iron Works, Sheffield.* |
| 1883 | Davy, David, *Broom Croft, Parkhead, Sheffield.* |

| Elected Member | |
|---|---|
| 1883 | Dawson, B., *York House, Malvern Link, Worcester.* |
| 1887 | Deacon, George Frederick, *Municipal Offices, Liverpool.* |
| 1887 | Dean, William, *Great Western Railway, Swindon.* |
| 1874 | Deby, Julien, 31 *Belsize Avenue, Hampstead, N.W.* |
| 1885 | Dees, James Gibson, *Floraville, Whitehaven.* |
| 1885 | *Deighton, Wm., *Grove House, Hunslet, Leeds.* |
| 1879 | Delorme, I., *Société de Montain à Outreau, Pas-de-Calais, France.* |
| 1881 | Denne, Thos. M., *Dufferin Street, London, S.E.* |
| 1880 | Dennis, W. F., 101 *Leadenhall Street, London, E.C.* |
| 1880 | Dering, G. E., *Lockleys, Welwyn, Herts.* |
| 1889 | Devereux, Walter B., *Colorado, U.S.A.* |
| 1869 | *Devonshire, The Duke of, K.G., *Holker Hall, Grange, Lancashire.* |
| 1879 | Dick, G. Alex., 110 *Cannon Street, London, E.C.* |
| 1884 | Dick, Frank Wesley, *Newton Steel Works, Newton, near Glasgow.* |
| 1876 | Dickinson, Samuel, *Newbridge, Wolverhampton.* |
| 1889 | Dickinson, Edward, *Meersbrook Bank, Sheffield.* |
| 1884 | Dickinson, John, *Park House, Sunderland.* |
| 1888 | Dickinson, Richard Elihu, 17 *Croft Terrace, Jarrow.* |
| 1889 | Dickson, John, *Glaisdale Iron Works, Grosmont, Yorkshire.* |
| 1881 | Dixon, A. A., 24 *Queen Victoria Street, London, E.C.* |
| 1880 | Dixon, D. W., *Brotton Mines, Saltburn-by-the-Sea.* |
| 1874 | Dixon, Joseph, 80 *Moika, St. Petersburg, Russia.* |
| 1869 | *Dixon, Raylton, *Cleveland Iron Shipyard, Middlesbrough.* |
| 1884 | Dodd, Benj., *Bearpark Colliery, County Durham.* |

| Elected Member | |
|---|---|
| 1869 | *Dodds, Joseph,<br>*Stockton-on-Tees.* |
| 1872 | Dodds, Matthew B.,<br>*Stockton-on-Tees.* |
| 1885 | Donald, Wm. J. Alex.,<br>27 *St. Vincent Place, Glasgow.* |
| 1874 | Dorman, A. J.,<br>*Middlesbrough.* |
| 1870 | Douglas, C. P.,<br>*Parliament Street, Consett, Durham.* |
| 1875 | Dove, George, Jun.,<br>*Hatfield House, Hatfield, near Doncaster.* |
| 1869 | *Downey, Alfred C.,<br>*Coatham Iron Works, Middlesbrough.* |
| 1877 | Downie, Alexander,<br>*The Ashes, Stanhope, Weardale.* |
| 1881 | Downing, Samuel,<br>*Morlands, Sutton Road, Erdington, Birmingham.* |
| 1889 | Dreux, A.,<br>*Acieries de Longwy, Mont St. Martin, France.* |
| 1888 | Dronsfield, William,<br>*Alexandra Park, Oldham.* |
| 1885 | Drown, Thomas M.,<br>*Institute of Technology, Boston, U.S.A.* |
| 1886 | Dudley, Charles B.,<br>*Altoona, Pennsylvania, U.S.A.* |
| 1889 | Duncan, David John Russell,<br>10 *Airlie Gardens, Kensington, W.* |
| 1888 | Dunkerley, C. Chorlton,<br>*Hurst Dale, Bowden.* |
| 1888 | Dunlop, Alexander M.,<br>11 *Norfolk Street, Park Lane, London, W.* |
| 1875 | Dunnachie, James,<br>*Glenboig, near Coatbridge, N.B.* |
| 1877 | Du Pre, Francis Baring,<br>*Oakwood, Chichester.* |
| 1875 | Durfee, Wm. F.,<br>*Pennsylvania Diamond Drill Coy., Birdsboro', Berks County, U.S.A.* |
| 1881 | Durham, The Earl of,<br>*Lambton Castle, Fence Houses, Co. Durham.* |
| 1884 | Durieux, Aimé,<br>18 *Avenue Matignon, Paris.* |
| 1884 | Dyer, H. S.,<br>*Condercum House, Newcastle-on-Tyne.* |
| 1875 | Dyson, George,<br>*Middlesbrough.* |

| Elected Member | |
|---|---|
| 1885 | Eadon, Robt. Renton,<br>*President Works, Sheffield.* |
| 1882 | Eagland, W. H.,<br>*74 Wellington Street, Leeds.* |
| 1886 | Earle, Wm. Norcliffe,<br>*Cwm Avon, Port Talbot, S. Wales.* |
| 1882 | Easton, Edward,<br>*Delahay Street, Westminster, S.W.* |
| 1887 | Eccles, Herbert,<br>*Cwm Avon, Port Talbot, Glamorganshire.* |
| 1880 | Edge, John H.,<br>*Coalport Works, Shifnal, Salop.* |
| 1884 | Edmonds, R.,<br>*Royal Arsenal, Woolwich.* |
| 1889 | Edwards, Daniel,<br>*Morriston, R.S.O., Glamorganshire.* |
| 1889 | Edwards, Wm. Henry,<br>*Morriston, R.S.O., Glamorganshire.* |
| 1887 | Egleston, Thomas,<br>*School of Mines, Columbia College, New York, U.S.A.* |
| 1880 | Ehrhardt, B.,<br>*Cainsdorf, Saxony.* |
| 1883 | Ellacott, Robert H.,<br>*Engineering Works, Plymouth.* |
| 1877 | Elliot, Sir George, Bart., M.P.,<br>*23 Great George Street, London, S.W.* |
| 1885 | Ellis, Arthur D.,<br>*Bowling Iron Company, Bradford, Yorks.* |
| 1889 | Ellis, Arthur Stanley,<br>*Nova Scotia Steel Coy., Ld., New Glasgow, Nova Scotia.* |
| 1883 | Ellis, E. William,<br>*Church Place, New Swindon, Wilts.* |
| 1875 | Ellis, J. D.,<br>*Atlas Works, Sheffield.* |
| 1884 | Ellis, T. L.,<br>*North British Iron Works, Coatbridge, N.B.* |
| 1879 | Ellison, John,<br>*Rose Hill, Harrington, Cumberland.* |
| 1874 | Euchene, Albert,<br>*50 Rue de Moscow, Paris.* |
| 1882 | Evans, Christmas,<br>*Heolgerrig, Merthyr Tydfil.* |
| 1873 | Evans, David,<br>*Barrow Steel Works, Barrow-in-Furness.* |
| 1889 | Evans, Evan D.,<br>*Barrow Steel Works, Barrow-in-Furness.* |
| 1881 | Evans, J Campbell,<br>*Parliament Mansions, Victoria Street, London, S.W.* |

Elected Member

1878 Evans, Richard,
*Consett Iron Works, Consett, Durham.*

1884 Evans, R. K.,
*Whiston Grange, Rotherham.*

1869 *Evans, William,
*Bowling Iron Works, Bradford, Yorkshire.*

1882 Evans, William,
*Cyfarthfa Iron and Steel Works, Merthyr Tydfil, Glamorganshire.*

1883 Evans, W.,
*The Cliff, Ferryside, Carmarthenshire.*

1889 Evrard, Alfred,
19 *Boulevard des Italiens, Paris.*

1869 *Farley, Reuben,
*Summit Foundry, West Bromwich.*

1869 *Farnworth, William,
*Swinden Iron Works, Dudley.*

1877 Faustman, E.,
*Care of T. Nordenfelt,* 53 *Parliament Street, London, S.W.*

1872 Faviell, F. H.,
52 *Leadenhall Street, London, E.C.*

1886 Fearnehough, Walter,
*Garden Street, Sheffield.*

1886 Feldtmann, Rudolph,
116 *St. Vincent Street, Glasgow.*

1889 Fellows, Samuel James,
*Compton, Wolverhampton.*

1889 Ferguson, Chas. Wm.,
*Greenock Road, Buchanan Street, Paisley.*

1885 Finlayson, Finlay,
*Vulcan Foundry, Coatbridge, N.B.*

1889 Firbank, Joseph Tom,
*Railway Approach, London Bridge, S.E.*

1888 Firth, Ambrose,
*Newhall Iron Works, Sheffield.*

1882 Firth, Lewis J.,
*Norfolk Works, Sheffield.*

1889 Firth, Wm. Edgar,
*Midvale Steel Coy., Nicetown, Philadelphia, U.S.A.*

1881 Fischer, M. F.,
*Halleschestrasse* 9, *Magdeburg, Germany.*

1883 Fisher, Edward,
*Hill Crest, Market Harborough.*

1870 Fisher, E. K.,
*Market Harborough.*

Elected Member

1883 Fitzsimons, Edward,
*3 St. James Terrace, Barrow-in-Furness.*

1887 Flagler, John H.,
*104 John Street, New York.*

1881 Flather, William T.,
*Love Street Steel Works, Sheffield.*

1883 Fleming, John,
*32 Grainger Street (West), Newcastle-on-Tyne.*

1886 Fleming, Robt.,
*Atlas Works, Bathgate, Glasgow.*

1877 Fletcher, W.,
*Brigham Hill,* viâ *Carlisle.*

1885 Fletcher, Wm.,
*Eagle Foundry, Booth Street, Salford.*

1872 Forester, W. H.,
*Sketty Park, Swansea.*

1883 Forster, G. Baker,
*Lesbury, R. S. O., Northumberland.*

1879 Forsyth, Robert,
*Union Steel Co., Chicago, U.S.A.*

1874 Fossick, William G.,
*86 Cannon Street, London, E.C.*

1880 Foster, H. Le Neve,
*c/o Bolckow, Vaughan & Co., South Bank, Middlesbrough.*

1869 *Foster, W. O., M.P.,
*Stourbridge Iron Works, Stourbridge.*

1879 Fould, Alphonse,
*Pompey, Meurthe-et-Moselle, France.*

1884 Fownes, Hy.,
*Tyne Forge Company, Ouseburn, Newcastle-on-Tyne.*

1877 Fox, Samson,
*Leeds Forge Company, Armley, Leeds.*

1886 Franki, James Peter,
*Morts Dock and Engineering Co., Sydney, N.S.W.*

1888 Fraser, Graham,
*Nova Scotia Steel Works, New Glasgow, Nova Scotia.*

1889 Freeston, Thomas Edgar,
*Attercliffe, Sheffield.*

1882 Freir, William E.,
*44A Cannon Street, London, E.C.*

1873 French, William
*59 St. Vincent Street, Glasgow.*

1886 Frew, John,
*Langloan Iron Works, Coatbridge, N.B.*

1881 Frey, C. A. von,
*I. Maximilianstrasse 2, Vienna, Austria.*

1882 Fromm, E.,
*Maximilianhütte,* Regensberg, *Bavaria.*

Elected Member

1879 Fry, John E.,
*Springfield Iron Works, Illinois, U.S.A.*

1869 *Fry, Theodore, M.P.,
*Darlington.*

1884 Galbraith, Wm.,
*Shelton Iron and Steel Co., Stoke-on-Trent.*

1882 Galloway, Arthur Walton,
*Knott Mill Iron Works, Manchester.*

1870 Galloway, Charles John,
*Knott Mill Iron Works, Manchester.*

1885 Galloway, Ed. N.,
*Knott Mill Iron Works, Manchester.*

1875 Galloway, John, Jun.,
*Knott Mill Iron Works, Manchester.*

1882 Galton, Sir Douglas, C.B., D.C.L., F.R.S.,
12 *Chester Street, Grosvenor Place, London.*

1888 Gamble, Joseph,
*Sheffield.*

1879 Gargan, Baron de,
*Hayange, Alsace-Lorraine, Germany.*

1884 Garrett, Geo.,
*Waverley Iron and Steel Works, Coatbridge, N.B.*

1889 Garrison, F. Lynwood,
*South-East Corner, 4th Chestnut Street, Philadelphia, U.S.A.*

1875 Gautier, Ferdinand,
3 *Rue Legendre, Parc Monceau, Paris.*

1888 Gayley, James,
*Edgar-Thomson Steel Works, Pittsburgh, U.S.A.*

1884 Geen, Geo.,
*Ivor Villa, Gold Tops, Newport, Monmouthshire.*

1875 Gilchrist, P. C.,
*Frognal Bank, Finchley New Road, Hampstead, N.W.*

1869 *Gilkes, Gilbert,
*Morny Hills, Kendal.*

1870 Gill, William,
*Norwood Lodge, Middlesbrough.*

1881 Gill, William,
*Orconera Iron Company, Bilbao, Spain.*

1872 Gillott, Thomas,
*Butterley Iron Works, Alfreton, Derbyshire.*

1872 Gilmour, Allan,
*Maryport Ironworks, Maryport.*

1886 Gilmour, Allan, Jun.,
*Maryport Iron Works, Maryport.*

1869 *Gjers, John,
*Ayresome Iron Works, Middlesbrough.*

| Elected Member | |
|---|---|
| 1882 | Gjers, Lawrence F.,<br>*3 Southfield Villas, Middlesbrough.* |
| 1886 | Gledhill, John M.,<br>*Sir Joseph Whitworth & Co., Manchester.* |
| 1885 | Glover, Ben Bradshaw,<br>*Beech Bank, Newton-le-Willows, Lancashire.* |
| 1879 | Goldsworthy, R. B.,<br>*Hulme, Manchester.* |
| 1871 | Goldwyer, John E.,<br>*Witford House, Briton Ferry, Glamorganshire.* |
| 1885 | Goodchap, Charles A.,<br>109 *Jermyn Street, London, S.W.* |
| 1886 | Goransson, A. H.,<br>*Sandviken Steel Works, Sweden.* |
| 1887 | Gordon, Alex.,<br>*Hamilton, Ohio, U.S.A.* |
| 1881 | Gordon, Andrew,<br>*Cransley Iron Works, Kettering.* |
| 1885 | Gordon, Fred. W.,<br>226 *Walnut Street, Philadelphia, Pa., U.S.A.* |
| 1873 | Gordon, Joseph G.,<br>*Queen Anne's Mansions, S.W.* |
| 1880 | Gössell, O., Jun.,<br>110 *Cannon Street, London, E.C.* |
| 1878 | Gottschalk, Alexandre,<br>13 *Rue Auber, Paris.* |
| 1887 | Goudie, Robert,<br>14 *Alloway Place, Ayr, N.B.* |
| 1887 | Goulty, Wallis Rivers,<br>*Albert Chambers, Albert Square, Manchester.* |
| 1889 | Graham, Alexander Macdougal,<br>20 *Dixon Street, Glasgow.* |
| 1886 | Grant, T. Maxwell,<br>*Windlass Engine Works,* 100 *Hydepark Street, Glasgow.* |
| 1869 | *Granville, Earl, K.G.,<br>*Walmer Castle, Deal, Kent.* |
| 1888 | Grazebrook, Michael Hickman,<br>*Netherton Iron Works, Dudley.* |
| 1888 | Green, Sir Edward, Bart.,<br>*Wakefield.* |
| 1886 | Green, Edward Llewellyn,<br>*Fairy Land, Neath, South Wales.* |
| 1881 | Green, John,<br>*Tin Plate Works, Abercarn, Monmouthshire.* |
| 1885 | Greenwood, William Henry,<br>*Birmingham Small Arms and Metal Company, Adderley Park Works, Birmingham.* |

| Elected Member | |
|---|---|
| 1889 | Gregory, Joseph,<br>*Whalley Cottage, Upper Chorlton Road, Manchester.* |
| 1875 | Greig, David,<br>*Steam Plough Works, Leeds.* |
| 1876 | Greiner, A.,<br>*Société John Cockerell, Seraing, Belgium.* |
| 1887 | Griffin, S.,<br>*Cleveland House, Bath.* |
| 1884 | Griffith, W.,<br>*Sheffield.* |
| 1886 | Griffiths, Azariah,<br>*Clyde Cottage, Falkirk, N.B.* |
| 1874 | Griffiths, N. R.,<br>*Wrexham.* |
| 1872 | Griswold, Chester,<br>11 *Pine Street, New York, U.S.A.* |
| 1869 | *Grove, Edwin,<br>*Brendon View, Stow Park, Newport, Monmouthshire.* |
| 1879 | Gruson, H.,<br>*Buckau, Magdeburg, Germany.* |
| 1875 | Guest, Josiah,<br>*Victoria and Albert Iron Foundries, West Bromwich.* |
| 1889 | Gubbins, R. R.,<br>*North Kent Iron Coy., Erith, Kent.* |
| 1888 | Guilleaume, Theodor,<br>*Mulheim-on-the-Rhine, Germany.* |
| 1882 | Guilleaume, Emil,<br>*Carlswerk, Mulheim-on-Rhine, Germany.* |
| 1875 | Gunther, William,<br>*Central Engineering Works, Oldham.* |
| 1883 | Gutmann, Max Ritter von,<br>*I Kantgasse*, 6, *Vienna, Austria.* |
| | |
| 1878 | Haarmann, August,<br>*Osnabrück Iron and Steel Works, Osnabrück, Prussia.* |
| 1887 | Hackney, Samuel John,<br>*Bott & Hackney, New Islington, Manchester.* |
| 1885 | Hadfield, Robt. Abbott,<br>*Ashdell, Sheffield.* |
| 1875 | Hagerman, J. J.,<br>*Colorado Springs, Colorado, U.S.A.* |
| 1884 | Haggie, D. H.,<br>*Sunderland.* |
| 1889 | Haggie, Peter Sinclair,<br>*Gateshead-on-Tyne.* |
| 1878 | Hall, J. F.,<br>*Norbury, Pitsmoor, Sheffield.* |

Elected Member

1872 Hall, William F.,
*Haswell Colliery, Fence Houses, Durham.*

1888 Hallbauer, Joseph,
*Lauchhammer Iron Works, Lauchhammer, Germany.*

1879 Hallopeau, P. F. A.,
*24 Rue de Lyon, Paris.*

1873 Halpin, Druitt,
*9 Victoria Chambers, London, S.W.*

1885 Hamilton, James,
*Coltness Iron Works, Newmains, N.B.*

1881 Hammond, Robert,
*117 Bishopgate Street Within, London, E.C.*

1870 Hampton, Thomas,
*Barrow Hematite Steel Works, Barrow-in-Furness.*

1888 Haniel, Hugo,
*Haniel & Lueg, Dusseldorf, Germany.*

1880 Hannay, G. Kerr,
*Hill Fort, Ulverston.*

1875 Hansell, R. B.,
*Moor Oaks Road, Broomhill, Sheffield.*

1884 Hansell, James Burne,
*Moor Oaks Road, Broomhill, Sheffield.*

1886 Hansell, Richard Alexander,
*The Canal Steel Works, Sheffield.*

1869 *Hanson, William,
*Newport Iron Works, Middlesbrough.*

1884 Harbord, F. W.,
*27 Mount Pleasant, Bilston, Staffordshire.*

1869 *Hardeman, Charles H.
*The Brampton, Newcastle-under-Lyne.*

1875 Harding, George,
*Biddulph Iron Works, Stoke-on-Trent.*

1875 Harding, Joshua,
*Norton Iron Works, near Burslem, Staffordshire.*

1883 Hardisty, John,
*c/o Bell Brothers, Middlesbrough.*

1889 Harris, Anthony,
*Grove Hill, Middlesbrough.*

1888 Harrison, George Herbert,
*Hagley, near Stourbridge.*

1876 Harrison G. K.
*Hagley, near Stourbridge.*

1882 Harrison, Wm. B.,
*Cyclops Iron Works, Walsall.*

1877 Hart, John,
*New Exchange Buildings, Middlesbrough.*

1888 Hartington, Right Hon. the Marquis of, M.P.,
*Devonshire House, London.*

| Elected Member | |
|---|---|
| 1876 | Hartley, Jno., *Heely, Sheffield.* |
| 1884 | Hartman, John M., 1235 *North Front Street, Philadelphia, U.S.A.* |
| 1881 | Hartmann, Jean, *Longwy, Moselle, France.* |
| 1888 | Harvey, Alfred, 6 *Mount Pleasant, Darlington.* |
| 1888 | Harvey, Charles, *Globe Steel Works, Sheffield.* |
| 1876 | Harvey, Wm., *Thornlee Park Villa, Wishaw, near Glasgow.* |
| 1882 | Haswell, Chas. J. F., *Theresianumgasse*, 10, *Vienna, Austria.* |
| 1879 | Hatton, William, *Hill Grove, Kidderminster.* |
| 1875 | Hatton, Geo., *The Lawn, Hagley, Stourbridge.* |
| 1876 | Hawdon, William, *Newport Iron Works, Middlesbrough.* |
| 1882 | Hawksley, Chas., 30 *Great George Street, Westminster, S.W.* |
| 1883 | Hawksley, G. W., *Brightside Engine Works, Sheffield.* |
| 1882 | Hawksley, Thos., F.R.S., 30 *Great George Street, Westminster, S.W.* |
| 1886 | Hay, Alex. Marshall, 37 *Walbrook, E.C.* |
| 1882 | Hay, Alexander S., *Nettlestone, South Hampstead.* |
| 1887 | Hayes, Edmund, *Union Bridge Company, Buffalo, U.S.A.* |
| 1869 | *Head, Charles A., *Teesdale Iron Works, Stockton-on-Tees.* |
| 1882 | Head, H. E., *c/o Conway Brothers, Newport, Monmouthshire.* |
| 1869 | *Head, Jeremiah, *Newport Rolling Mills, Middlesbrough.* |
| 1884 | Head, John, F.G.S. 12 *Queen Anne's Gate, Westminster, S.W.* |
| 1881 | Heath, A. H., *Madeley Manor, Newcastle, Staffordshire.* |
| 1873 | Heath, James, *Clayton Hall, Newcastle, Staffordshire.* |
| 1869 | *Heath, Robert, *Biddulph Iron Works, Stoke-on-Trent.* |
| 1872 | Heath, Robert, Jun., *Biddulph Iron Works, Stoke-on-Trent.* |

| Elected Member | |
|---|---|
| 1875 | Heathfield, R., *Foxlydiate, near Redditch.* |
| 1880 | Hedley, Robt., *Tudhoe Iron Works, Spennymoor.* |
| 1873 | Hedley, Thomas, 2 *Fenham Terrace, Newcastle-on-Tyne.* |
| 1884 | Helder, Aug., *Whitehaven, Cumberland.* |
| 1884 | Hellon, Robt., 47 *New Lowther Street, Whitehaven.* |
| 1878 | Helmholtz, Otto, *Director of the "Gesellschaft für Stahl Industrie," Bochu Germany.* |
| 1877 | Helson, Cyriaque, *Etablissements Metallurgiques de MM. Vardy et Bene Savona, Italy.* |
| 1889 | Henderson, Norman M'Farlane, *Broxburn Lodge, Broxburn.* |
| 1889 | Henning, Gustavus, 16 *Cedar Street, New York, U.S.A.* |
| 1884 | Heslop, C., *Upleatham Mines, Upleatham, R.S.O., Yorkshire.* |
| 1869 | *Hewlett, Alfred, *Kirkless Hall Iron Works, Wigan.* |
| 1873 | Hewlett, W. H., *Wigan Coal and Iron Company, Wigan.* |
| 1879 | Heywood, H., *Cardiff.* |
| 1879 | Hick, John, M.P., *Mytton Hall, Whalley, Blackburn.* |
| 1879 | Hickman, A., M.P., 22 *Palace Gardens, Kensington, W.* |
| 1883 | Hickman, A. W., *Spring-Vale Furnaces, Wolverhampton.* |
| 1881 | Higginbottom, James, *Seel Street, Liverpool.* |
| 1879 | Higson, Jacob, 68 *New Bridge Lane, Stockport.* |
| 1869 | *Hill, Alfred C., *Southbank, R. S. O., Yorkshire.* |
| 1878 | Hill, Francis, *Stocksbridge, near Sheffield.* |
| 1885 | Hill, John, 4 *Oxford Terrace, Stockton-on-Tees.* |
| 1886 | Hill, Joseph, 6 *Hartington Street, Barrow-in-Furness.* |
| 188[illegible] | Hills, Arnold F., *Thames Iron Works, London.* |

| Elected Member | |
|---|---|
| 1874 | Hilton, Franklin,<br>*Bolckow, Vaughan, & Co., Middlesbrough.* |
| 1885 | Hinchliffe, John,<br>*Bullhouse Colliery, Penistone.* |
| 1883 | Hingley, B., M.P.,<br>*Netherton Iron Works, Dudley.* |
| 1889 | Hingley, George Benjamin,<br>*Netherton Iron Works, Dudley.* |
| 1886 | Hirst, Daniel Jones,<br>*Dowlais Iron Works, Dowlais.* |
| 1874 | Hobson, Henry,<br>*Park House, Park Road, Jarrow-on-Tyne.* |
| 1879 | Hobson, J. F.,<br>*Washington, County Durham.* |
| 1884 | Hodges, P.,<br>238 *Barnsley Road, Sheffield.* |
| 1878 | Hodgson, John,<br>*North Terrace, Darlington.* |
| 1873 | Hodgson, John Lee,<br>*Hooley Range, Heaton-Moor, Stockport.* |
| 1886 | Hodson, James,<br>*Stoke-on-Trent.* |
| 1887 | Holgate, Thos. Edward,<br>146 *Blackburn Road, Darwen.* |
| 1874 | Holland, C. B.,<br>*Ebbw Vale Works, Newport, Mon.* |
| 1889 | Hollingworth, James,<br>*Dobcross, Oldham.* |
| 1873 | Hollingsworth, A. T.,<br>36 *Bedford Street, Strand, W.C.* |
| 1880 | Hollis, H. W.,<br>*North Lodge, Darlington.* |
| 1876 | Holste, Carl,<br>16 *Rupert Street, St. James's, London, W.* |
| 1876 | Holt, Henry Percy,<br>*The Cedars, Didsbury, Manchester.* |
| 1871 | Homer, Charles J.,<br>*Ivy House Stoke-upon-Trent.* |
| 1873 | Hopkinson, John,<br>*Inglewood, St. Margaret's Road, Bowden, Cheshire.* |
| 1886 | Horsborough, Robert,<br>*Southfield, Uddingston, near Glasgow.* |
| 1879 | Horsfall, G. H., Jun.,<br>*Larkfield, Toxteth Park, Liverpool.* |
| 1876 | Horsfall, Hodgson,<br>27 *Belgrave Road, London, S.W.* |
| 1888 | Horsfield, Arthur,<br>*High Bank, Horbury, near Wakefield.* |

| Elected Member | |
|---|---|
| 1889 | Horsfield, Samuel, *Hallside Steel Works, Newton, N.B.* |
| 1888 | Horton, Enoch, *The Grange, Bescot, near Walsall.* |
| 1883 | Horton, S. B. L., *Park House, Shifnal, Salop.* |
| 1869 | *Horton, Thomas E., *Penmaenmawr, North Wales.* |
| 1885 | Hosking, Richard, *Clarence House, Dalton-in-Furness.* |
| 1873 | Houghton, John, *The Beeches, Moore, near Warrington.* |
| 1880 | Houldsworth, Jas., 36 *Queen's Gate, South Kensington, London.* |
| 1882 | Houldsworth, W. J., 36 *Queen's Gate, South Kensington, London.* |
| 1883 | Howie, Henry, *Harrington, Cumberland.* |
| 1869 | *Howson, R., *Exchange Place, Middlesbrough.* |
| 1884 | Hoyle, James Rossiter, *Norfolk Works, Sheffield.* |
| 1878 | Hoysradt, Jacob W., *Hudson, New York, U.S.A.* |
| 1880 | Huart, Baron F. d', *Longwy, Moselle, France.* |
| 1885 | Hudson, Wm. John, *Woodside Iron Works, Dudley.* |
| 1880 | Hudspeth, W., *Haltwhistle, Northumberland.* |
| 1882 | Huggett, J. A., *Plasket House, Grand Parade, Eastbourne.* |
| 1877 | Hughes, Arthur D., *care of* F. Taylor, 35 *Queen Victoria Street, London, E.C.* |
| 1878 | Hughes, John, *care of* F. Taylor, 35 *Queen Victoria Street, London, E.C.* |
| 1888 | Hughes, John James, 35 *Queen Victoria Street, London, E.C.* |
| 1882 | Hughes, Wm., 19 *Lionel Street, Birmingham.* |
| 1887 | Hulse, J. Whitworth, *Ordsal Works, Salford, Manchester.* |
| 1882 | Hulse, Wm. W., *Ordsal Tool Works, Salford, Manchester.* |
| 1872 | Humphreys, A. W., 45 *William Street, New York, U.S.A.* |
| 1888 | Hunt, Alfred E., 95 *Fifth Avenue, Pittsburgh, U.S.A.* |

Elected Member

1889 Hunt, Charles,
*Windsor Street, Birmingham.*

1881 Huntington, Alfred Kirby,
*King's College, London, W.C.*

1876 Hurll, Jno.,
*Woodneuk, Gartcosh, P.O., Glasgow.*

1882 Hutchinson, Thomas C.,
*Hilda House, Middlesbrough.*

1889 Hutchinson, William,
*Staffordshire Steel Company, Bilston.*

1883 Hutton, A. W.,
*Cyclops Iron Works, Walsall.*

1876 Hutton, Robert,
*Batts Foundry, Whitby.*

1875 Ianson, James,
*Fairfield House, Darlington.*

1869 *Ianson, J. C.,
*Glenholme, Saltburn-by-the-Sea.*

1876 Ingham, William P.,
*Middlesbrough.*

1883 Ingram, C. W.,
*Falconhyrst, Penarth, Cardiff.*

1884 Jacks, William,
7 *Royal Bank Place, Glasgow.*

1881 Jackson, John,
*Stubben Edge, Chesterfield.*

1873 Jackson, W. F.,
*Herndale House, Litton,* viâ *Stockport.*

1881 Jacobi, Hugo,
*Gutehoffnungshütte, Westphalia, Germany.*

1869 *Jaffrey, G. W.,
*Westland Terrace,* 17 *Robertson Street, Greenock.*

1885 Jambille, Louis,
*Maubeuge, France.*

1889 James, Charles Henry,
8 *Courtland Terrace, Merthyr Tydfil.*

1889 James, Enoch,
*Rhymney Iron Works, Rhymney, Monmouthshire.*

1873 James, Phineas,
*Abercarn Estate Office, Abercarn, Newport, Mon.*

1884 James, J. W. Hy.,
2 *Victoria Mansions, Westminster, S.W.*

1883 Jamme, G.,
*Dayton, Tennessee, U.S.A.*

| Elected Member | |
|---|---|
| 1884 | Jameson, John, *Akenside Hill, Newcastle-on-Tyne.* |
| 1889 | Jamieson, James Fleming Fyfe, 9 *Queen's Gate, London, S.W.* |
| 1889 | Jaques, Wm. Hy., *Bethlehem Iron Company, Bethlehem, Pa, U.S.A.* |
| 1877 | Jeans, J. S., *Victoria Mansions, Victoria Street, S.W.* |
| 1879 | Jefferies, J. R., *Ipswich.* |
| 1888 | Jeffreys, Edward Homer, *Hawkshill, Chapel Allerton, Leeds.* |
| 1876 | Jenkins, A. T., *Masbro' Boiler Works, Rotherham.* |
| 1872 | Jenkins, James G., 33 *Renfield Street, Glasgow.* |
| 1869 | *Jenkins, Sir J. J., *The Grange, Swansea.* |
| 1869 | *Jenkins, William, *Consett Iron Works, Consett, County Durham.* |
| 1874 | Jenkins, William, *Dowlais Iron Works, Dowlais.* |
| 1885 | Jenks, Isaac James, *Cleveland Iron Works, Wolverhampton.* |
| 1887 | Jenks, Walter, *Minerva Works, Horseley Fields, Wolverhampton.* |
| 1882 | Jennings, Charles, *East Parade, Consett, County Durham.* |
| 1875 | Jennings, James, 3 *Ilminster Gardens, Lavender Hill, Clapham Junction, S* |
| 1871 | Johnson, Richard S., *Sherburn Hall, Durham.* |
| 1871 | Johnson, Thewlis, *Bradford Iron Works, Manchester.* |
| 1873 | Johnson, Walter, *Exchange Buildings, Middlesbrough.* |
| 1875 | Johnson, W. H., 26 *Lever Street, Manchester.* |
| 1880 | Johnston, James, *Disley, Cheshire.* |
| 1881 | Jonas, Joseph, *Continental Steel Works, Sheffield.* |
| 1882 | Jones, Alfred W., *Dashwood House, New Broad Street, E.C.* |
| 1870 | Jones, Benjamin, *Dowlais Iron Works, Dowlais.* |
| 1886 | Jones, Daniel Robert, *Dowlais Iron Works, Dowlais, Glamorganshire.* |

| Elected Member | |
|---|---|
| 1881 | Jones, Edwin,<br>141 *Cannon Street, London, E.C.* |
| 1869 | *Jones, Edwin F.,<br>*Normanby Iron Works, Middlesbrough.* |
| 1878 | Jones, Edwin While,<br>*Cleveland Steel Works, South Bank, Middlesbrough.* |
| 1874 | Jones, Ephraim A.,<br>*Ayrton Rolling Mills, Middlesbrough.* |
| 1884 | Jones, James Cecil,<br>*Rhymney Iron Works, South Wales.* |
| 1870 | Jones, John,<br>*Dowlais Iron Works, Dowlais.* |
| 1881 | Jones, Josepb,<br>*Corrugated Iron Works, Wolverhampton.* |
| 1881 | Jones, Wm. E.,<br>141 *Cannon Street, London, E.C.* |
| 1889 | Jopling, Thomas,<br>*Otis Iron and Steel Coy., Cleveland, Ohio, U.S.A.* |
| 1889 | Jordan, Albert Edward,<br>*Birchfield Lodge, Perry Barr, Birmingham.* |
| 1889 | Jordan, Andrew Jackson,<br>6, 8, 10 *Baker's Hill, Sheffield.* |
| 1874 | Jordan, Sampson,<br>5 *Rue Viètte, Quartier Monceaux, Paris.* |
| 1875 | Jordan, Thomas,<br>*Dunkirk Iron Works, West Bromwich.* |
| 1878 | Jouraffsky, Demetrius,<br>*St. Petersburg, Russia.* |
| 1889 | Jowitt, Charles Albert Renny,<br>*Scotia Works, Sheffield.* |
| 1882 | Jowitt, Thomas W.,<br>*Scotia Steel Works, Sheffield.* |
| 1879 | Justice, P. M.,<br>54 *Chancery Lane, London, W.C.* |
| 1888 | Kearsley, George,<br>*British Iron and Implement Works, Ripon.* |
| 1888 | Keay, Ernest Charles,<br>*Corporation Street, Birmingham.* |
| 1885 | Keen, Arthur,<br>*Beechfield, Ampton Road, Edgbaston, Birmingham.* |
| 1888 | Keighley, George,<br>*Bankhouse Iron Works, Burnley.* |
| 1874 | Kellett, William,<br>24 *King Street, Wigan.* |

| Elected Member | |
|---|---|
| 1886 | Kendall, J. Dixon,<br>*Roper Street, Whitehaven.* |
| 1884 | Kennard, H. J.,<br>20 *Hyde Park Terrace, London, W.* |
| 1883 | Kennedy, Professor A., F.R.S.,<br>*University College, London, W.C.* |
| 1888 | Kennedy, Myles,<br>*Hill Fort, Ulverston.* |
| 1881 | Kenrick, Geo. H.,<br>*Whelstone, Somerset Road, Edgbaston, Birmingham.* |
| 1883 | Kerpely, A. Ritter von,<br>*Buda Pesth, Hungary.* |
| 1886 | Kerr, Andrew,<br>*Ardeer, N.B.* |
| 1884 | Kidner, John,<br>*Islip House, Thrapston.* |
| 1884 | King, John William,<br>*Sheffield Steel and Iron Works, Sheffield.* |
| 1869 | *Kirk, Henry,<br>*Workington.* |
| 1874 | Kirk, Peter,<br>*Mossbay Iron Works, Workington.* |
| 1869 | *Kirkconel, John F.,<br>*Furnace House, Cleator Moor,* viâ *Carnforth, Cumberland* |
| 1888 | Kirkhouse, Edward Godwin,<br>*Consett Iron Works, Blackhill.* |
| 1883 | Kitching, A. E.,<br>*Elm Field, Darlington.* |
| 1881 | Kitching, John,<br>*Branksome Hall, Darlington.* |
| 1889 | Kitson, Albert Ernest,<br>*Monkbridge Iron Works, Leeds.* |
| 1885 | Kitson, Fredk. James,<br>*Monkbridge Iron Works, Leeds.* |
| 1869 | *Kitson, Sir James, Bart.,<br>*Monkbridge Iron Works, Leeds.* |
| 1879 | Koch, Charles,<br>*St. Chamond, Loire, France.* |
| 1878 | Koch, W. E.,<br>*Spang Iron and Steel Co., Sharpsburg, Pa., U.S.A.* |
| 1888 | Koch, Francis,<br>*Alexandrowsky Steel Works, St. Petersburg.* |
| 1884 | Koehler, Henry,<br>*Bochum, Westphalia, Germany.* |
| 1875 | Kolokoltzoff, Rear-Admiral,<br>*Oboukoff Steel Works, St. Petersburg, Russia.* |
| 1889 | Korb, Friddlin,<br>29 *Spring Hill Road, Sheffield.* |

| Elected Member | |
|---|---|
| 1889 | Korten, Rudolph,<br>*Messrs. Bolckow, Vaughan, & Co., South Bank, R.S.O., Yorkshire.* |
| 1883 | Krautner, Adolf,<br>*Vordernberg, Styria.* |
| 1886 | Kriete, Henry C.,<br>17 *Metropolitan Block, Chicago, U.S.A.* |
| 1880 | Kupelwieser, Paul,<br>*Witkowitz, Austria.* |
| 1874 | Laing, James,<br>*Sunderland.* |
| 1883 | Lancaster, Jno.,<br>*Anfield House, Leamington.* |
| 1874 | Lancaster, Joshua,<br>*Talladega Iron and Steel Company, Alabama, U.S.A.* |
| 1872 | Landale, Andrew,<br>*Echo Bank, Inverkeithing.* |
| 1881 | Langdon, Wm.,<br>*Huelva, Spain.* |
| 1877 | Larsen, Jno. Daniel,<br>67 *Belvedere Road, Upper Norwood, London, S.E.* |
| 1885 | Latinis, Victor,<br>*Directeur de la Société des forges d'Acoz, Acoz, France.* |
| 1888 | Lauder, George,<br>*Edgar-Thomson Steel Works, Pittsburg, U.S.A.* |
| 1876 | Lawson, Arthur T.,<br>*Beech Grove House, Leeds.* |
| 1869 | *Laybourne, Richard,<br>*Isca Foundry, Newport, Monmouthshire.* |
| 1873 | Ledger, Joseph,<br>*Castellette, Keswick.* |
| 1887 | Ledingham, L. Napier,<br>*Brightside Steel Works, Sheffield.* |
| 1887 | Lee, Arthur,<br>*Bessemer Road, Attercliffe, Sheffield.* |
| 1889 | Lee, Henry,<br>*Sedgley Park, Prestwich, Lancashire.* |
| 1874 | Lee, William,<br>139 *Cannon Street, London, E.C.* |
| 1873 | Lees, Eli,<br>102 *Lancaster Gate, London, W.* |
| 1887 | Lees, John Bayley,<br>*Oaklands, Church Lane, Handsworth.* |
| 1887 | Lees, Samuel,<br>*Beacon View, Hill Top, West Bromwich.* |

| Elected Member | |
|---|---|
| 1889 | Lees, Samuel, *Parkbridge, Ashton-under-Lyne.* |
| 1879 | Leigh, J., *Tabley House, Knutsford.* |
| 1888 | Leishman, John G. A., *Lewis Block, Pittsburg, U.S.A.* |
| 1880 | Leith, A. J., *Joliet Steel Co., Chicago, Illinois, U.S.A.* |
| 1882 | Lennard, J. Milner, *Middlesbrough-on-Tees.* |
| 1881 | Leo, L., *Bochum, Westphalia.* |
| 1878 | Lester, John Nicholls, *Bradford Iron Works, Walsall.* |
| 1887 | Lever, Ellis, *Bowden, Cheshire.* |
| 1870 | Leveson-Gower, Hon. E. F., M.P., *14 South Audley Street, London.* |
| 1870 | Levick, Frederick, *Cornhill Chambers, White Lion Court, Cornhill, E.C.* |
| 1869 | *Lewis, H. W., *Llwyn-yr-eas, Abercanaid, near Merthyr Tydfil.* |
| 1881 | Lewis, Henry, *Kingshurst, Sandwell, Handsworth, Birmingham.* |
| 1882 | Lewis, William B., *8 Victoria Chambers, Westminster, S.W.* |
| 1871 | Lewis, Sir William Thomas, *Mardy, Aberdare.* |
| 1886 | Liddell, G H., *Morseby Hall, Whitehaven.* |
| 1889 | Liddelow Charles *(Contractor for Railways), Carlisle.* |
| 1888 | Lindberg, Carl C., *Laxå, Sweden.* |
| 1874 | Lindheim, W. Von, *Lugeck, 3, Vienna.* |
| 188 | Lindow Jonas, *Ehen Hall, near Carnforth.* |
| 1881 | Lindsay, Thos. S., *31 Poultry, London, E.C.* |
| 1883 | Linnell, Arthur, *Holwell Iron Works, Melton Mowbray.* |
| 1882 | Lithman, Jos. E., *14 Fenchurch Street, E.C.* |
| 1881 | Little, George, *Messrs. Platt Brothers, Oldham.* |
| -- | Livesey James, *Broad Street Avenue, Blomfield Street, E.C.* |

Elected Member

1880 Ljungberg, E. J.,
*Falun, Sweden.*

1876 Llewellyn, F. W.,
*Shelton Bar Iron Works, Stoke-on-Trent.*

1869 *Lloyd, Francis H.,
*Wood Green, Wednesbury.*

1869 *Lloyd, Samuel,
*The Farm, Sparkbrook, Birmingham.*

1880 Lloyd, W. E.,
303 *Ickneild Port Road, Birmingham.*

1874 Lloyd, William Henry,
*Hall Green, Wednesbury.*

1869 *Lloyd, Wilson,
*Mywood House, Wednesbury.*

1875 Lones, Edward,
*Iron and Tin-plate Works, Lydney, Gloucestershire.*

1883 Lones, Jabez,
*Fern Lodge, South Road, Smethwick.*

1875 Long, A. de Lande,
*Stockton-on-Tees.*

1871 Longridge, R. B.,
*Yew Tree House, Tabley, near Knutsford.*

1875 Longridge, R. C.,
*Kibrie, Knutsford.*

1869 *Longsdon, Alfred,
9 *New Broad Street, E.C.*

1880 Looker, P. S., *care of* R. B. Looker,
43 *Finsbury Square, E.C.*

1889 Lopes, George,
*Engineer's Office, London, Brighton, and South Coast Railway, London Bridge, S.E.*

1880 Lorsbach, A.,
*Essen-on-the-Ruhr, Germany.*

1881 Louis, Henry,
*Manager, Cerro de Pasco Gold Field Coy., near Barberton, Transvaal.*

1874 Lowe, John E.,
2 *Lawrence Pountney Hill, London, E.C.*

1875 Lowood, John Grayson,
*Ganister Works, Sheffield.*

1888 Lucas, Richard Norman,
8 *Featherstone Buildings, High Holborn, W.C.*

1876 Lueg, Carl,
*Gütehoffnungshütte, Oberhausen, Westphalia.*

1882 Lueg, C. H.,
*Düsseldorf, Germany.*

1876 Lürmann, F. (Engineer),
*Osnabrück, Germany.*

| Elected Member | |
|---|---|
| 1884 | Lyon, Alfred C.,<br>*Southbank, Compton, Wolverhampton.* |
| 1888 | Lysaght, Wm. Royse,<br>*Swan Gardens Iron Works, Wolverhampton.* |
| 1884 | Macalpine, G. W.,<br>*Parkside, Accrington.* |
| 1883 | Macar, Baron Leon de,<br>*Arville par Poire Saint Hubert, Belgium.* |
| 1884 | Macarthy, G. E.,<br>*Ashfield House, Newcastle-on-Tyne.* |
| 1880 | Macco, H.,<br>*Siegen, Germany.* |
| 1889 | Macdonald, Kenneth,<br>*Rose Hill, Whitehaven.* |
| 1883 | Mackey, Wm. M'Donnel,<br>*Frodingham, near Doncaster.* |
| 1886 | Mackinnon, Wm.,<br>5 *Marlborough Terrace, Kelvinside, Glasgow.* |
| 1879 | Maclaran, R.,<br>*Dafin Tin Plate Works, Gilfig, Llanelly.* |
| 1888 | Maclaren, Robert, junr.,<br>*Eglinton Foundry, Glasgow.* |
| 1882 | Maclean, Andrew H.,<br>13 *Grosvenor Terrace, Glasgow.* |
| 1888 | MacLellan, George S.,<br>*Clutha Iron Works, Glasgow.* |
| 1886 | MacLellan, Wm. Turner,<br>*Clutha Iron Works, Glasgow.* |
| 1873 | Maclennan, Joseph,<br>*Bilbao, Spain.* |
| 1881 | Macnee, D.,<br>2 *Westminster Chambers, London, S.W.* |
| 1879 | Main, Robert,<br>*Ardeer Iron Works, Stevenston, Ayrshire.* |
| 1888 | Maitland, General, C.B.,<br>*Woolwich Arsenal, Woolwich.* |
| 1879 | Malo, Alberto,<br>*Guanjuato, Mexico.* |
| 1889 | Mallaband, John,<br>*Home Cottage, Pitsmoor, Sheffield.* |
| 1870 | Manby, Cordy,<br>*Wapell Wood, Bewdley.* |
| 1888 | Mannaberg, Max,<br>*Frodingham Iron Works, near Doncaster.* |
| 1879 | Margery, Jules,<br>*Aachener Hütte,* Rothe Erde, near Puy-la-Chapelle. |

| Elected Member | |
|---|---|
| 1885 | Marley, J. E., *Hebburn-on-Tyne.* |
| 1879 | Maroquin, A., *Couillet, near Charleroi, Belgium.* |
| 1887 | Marsden, Benjn., *Manchester Bolt and Nut Works, London Road, Manchester.* |
| 1873 | Marsh, T. E. M., *Engineer's Office, Hawthorn House, Bath.* |
| 1881 | Marsh, W. S., 109 *St. Helens Road, Swansea, Glamorganshire.* |
| 1878 | Marshall, David, *Glasgow Tube Works, Glasgow.* |
| 1880 | Marshall, F. H., *Ormesby Iron Works, Middlesbrough.* |
| 1889 | Marshall, Francis Carr, *Messrs. Hawthorn, Leslie, & Co., St. Peter's Works, Newcastle-on-Tyne.* |
| 1875 | Marshall, R. C., *Caldergrove, Newton, near Glasgow.* |
| 1888 | Marston, Edward, *Perseverance Iron Works, Pendleton, Manchester.* |
| 1883 | Marston, S., *North-Eastern Steel Works, Middlesbrough.* |
| 1876 | Martélet, M., 56 *Rue de Provence, Paris.* |
| 1879 | Martell, B., 2 *White Lion Court, Cornhill, London, E.C.* |
| 1882 | Marten, Edward B., *Stourbridge.* |
| 1869 | *Marten, Henry John, *The Birches, Codsall, near Wolverhampton.* |
| 1873 | Martin, A. H., *Dowlais, Glamorganshire.* |
| 1871 | Martin, Edward P., *Dowlais, Glamorganshire.* |
| 1883 | Martin, R., *Drumman Isaf, Llansamlet, Swansea.* |
| 1887 | Marvel, William D., 68 *and* 70 *William Street, New York, U.S.A.* |
| 1878 | Massenez, Joseph, *Hoerde, Westphalia.* |
| 1880 | Massey, W. H., *Twyford, Berks.* |
| 1887 | Mather, William, *Salford Iron Works, Manchester.* |
| 1889 | Matheson, Ewing, *Farnley Iron Works, near Leeds.* |

| Elected Member | |
|---|---|
| 1886 | Mathieson, Thomas A., *East Campbell Street, Glasgow.* |
| 1885 | Mathieu, Jean A., 51 *Moffat Block, Detroit, Michigan, U.S.A.* |
| 1888 | Matthews, John, *R. & W. Hawthorn, Leslie & Co. (Limited), Newcastle-on-Tyne.* |
| 1874 | Maw, William Henry, 36 *Bedford Street, Strand, London, W.C.* |
| 1881 | Maybery, Joseph, *Oldcastle Tin Plate Works, Llanelly.* |
| 1888 | Maybury, Edward, *Perseverance Iron Works, Pendleton, Manchester.* |
| 1887 | Mayer, Ernest, 9 *Rue Moncey, Paris.* |
| 1874 | Maynard, George W., 35 *Broadway, New York, U.S.A.* |
| 1869 | *Maynard, H. N., 7 *Westminster Chambers, London, S.W.* |
| 1884 | McCorkindale, Dr. D., *Clydesdale Iron and Steel Works, Mossend, Glasgow.* |
| 1884 | McCowan, Wm., *Roseneath, Whitehaven.* |
| 1886 | McDonald, Wm., *Carlyle Villa, Carlyle Road, Manor Park, Essex.* |
| 1883 | McDonnell A., *Wellesley, Warlingham, Surrey.* |
| 1883 | McLaren, Charles, 3 *New Court, Lincoln's Inn, London.* |
| 1871 | M'Clelland, Andrew S., 115 *St. Vincent Street, Glasgow.* |
| 1889 | M'Creath, Andrew S., *Harrisburg, Pennsylvania, U.S.A.* |
| 1878 | M'Creath, James, 95 *Bath Street, Glasgow.* |
| 1888 | M'Gowan, Wm., *Whitehaven.* |
| 1889 | M'Murty, George Gibson, *Apollo Iron and Steel Company, Pittsburg, U.S.A.* |
| 1874 | M'Pherson, George, *Wednesbury Oak Iron Works, Tipton.* |
| 1880 | Melling, Samuel, *Ince Forge Company, Wigan.* |
| 1886 | Melling, Thomas, *Ince Forge, Wigan.* |
| 1874 | Mellon, Henry, *Ireleth, Askam-in-Furness.* |

| Elected Member | |
|---|---|
| 1883 | Melnhof, Baron F. Mayr von, *Operngasse*, 4, *Vienna, Austria.* |
| 1878 | Merritt, W. H., 34 *St. George Street, Toronto, Canada.* |
| 1886 | Miller, J. Ritchie, 2 *Somerset Place, Glasgow.* |
| 1886 | Miller, Thomas, *London Road Foundry, Edinburgh.* |
| 1882 | Miller, John F., *Vulcan Foundry, Coatbridge, N.B.* |
| 1889 | Millward, George Anthony, 41 *Church Hill, Wednesbury.* |
| 1875 | Milner, Walter, *Whitecross Wire Works, Warrington.* |
| 1870 | Mitchell, Charles, *Newcastle-on-Tyne.* |
| 1873 | Mitchinson, H. S., *Bowling Iron Works, Bradford, Yorkshire.* |
| 1884 | Molineaux, W., *Capponfield Iron Works, Bilston.* |
| 1870 | Monks, F., *Walton Old Hall, near Warrington.* |
| 1873 | Moon, Richard, Jun., *Penyvael, Llanymynech, near Oswestry.* |
| 1881 | Moore, Alfred, *Fitzroy Works, Euston Road, London, N.W.* |
| 1876 | Moore, Arthur C., *Ida Wharf, Black Horse Bridge, Deptford, S.E.* |
| 1882 | Moore, William, *Leeds Steel Works, Leeds.* |
| 1875 | Morel, Ernest, *Tilleul Rolling Mills, Maubeuge, France.* |
| 1880 | Morgan, C. H., *Worcester, Mass., U.S.A.* |
| 1881 | Morgan, James Henry, 124 *Narrow Street, Limehouse, London, E.* |
| 1882 | Morgan, Thomas R., *Alliance, Ohio, U.S.A.* |
| 1888 | Morgan, Septimus Vaughan, 42 *Cannon Street, London, E.C.* |
| 1882 | Morris, Claude John, *The Mount, Altrincham.* |
| 1883 | Morris, Wm. H., 400 *Chestnut Street, Philadelphia, U.S.A.* |
| 1874 | Morrison, Martin, *Middlesbrough.* |
| 1873 | Morton, E. H., *Glenbrook, Cearn's Road, Oxton, Cheshire.* |

| Elected Member | |
|---|---|
| 1879 | Morton, James, *8 Princes Square, Buchanan Street, Glasgow.* |
| 1879 | Morton, James, *Manor Park, Blairhill, Coatbridge, N.B.* |
| 1889 | Moses, Edmund Bamford, *Cwm Avon, Glamorganshire.* |
| 1875 | Mosley, Col. Paget, *27 St. James' Square, London, S.W.* |
| 1882 | Mottram, Richard, *Knott Mill Iron Works, Manchester.* |
| 1886 | Mudd, Thomas, *Hartlepool.* |
| 1883 | Muirhead, Wm., *Parkhead Forge, Glasgow.* |
| 1871 | Müller, Charles Emile, *Middlesbrough.* |
| 1881 | Müller, R. W. Maxwell, *Scarboro' and Whitby Railway, Scarborough.* |
| 1889 | Müller, Thomas Neil, *Messrs. Müller & Co., Exchange Buildings, Middlesbrough.* |
| 1885 | Murisier, Oscar, *Acieries d'Alexandrowsky, St. Petersburg.* |
| 1871 | Musgrave, Jno., *Globe Iron Works, Bolton.* |
| 1871 | Musgrave, Joseph, *Globe Iron Works, Bolton.* |
| 1888 | Myers, W. Beswick, *14 Victoria Street, London, S.W.* |
| | |
| 1889 | Naylor, John William, *Wellington Foundry, Leeds.* |
| 1883 | Naylor, W., *Penistone, near Sheffield.* |
| 1888 | Needham, John, *13 Cannon Street, Manchester.* |
| 1869 | *Neesham, George, *Middlesbrough.* |
| 1875 | Neilson, George, *Summerlee Iron Works, Coatbridge, N.B.* |
| 1882 | Neilson, Hugh, Jun., *Clyde Bridge Steel Works, Cambuslang, N.B.* |
| 1874 | Neilson, James, *Mossend Works, Holytown Station, N.B.* |
| 1869 | *Neilson, John, *Summerlee, Coatbridge, N.B.* |

| Elected Member | |
|---|---|
| 1882 | Neilson, John A., *Summerlee Iron Works, Coatbridge, N.B.* |
| 1880 | Neilson, Walter, Jun., *Conservative Club, Glasgow.* |
| 1881 | Neilson, Walter, Jun., *Woodfield, Finedon, Wellingborough.* |
| 1888 | Nettlefold, John Sutton, *Castle Works, Tydu, Newport, Monmouthshire.* |
| 1887 | Newbigging, Thomas, *Manchester.* |
| 1888 | Nicholls, Thomas, *Cockin Villa, Barrow-in-Furness.* |
| 1888 | Nicholson, Henry, 37 *Stockton Street, Moss Side, Manchester.* |
| 1889 | Nicholson, James Percival *Bowling Iron Works, Bradford, Yorks.* |
| 1885 | Noble, James, *Grosvenor Terrace, Linthorpe Road, Middlesbrough.* |
| 1877 | Norbury, William Edward, *Knott Mill Iron Works, Manchester.* |
| 1873 | Nordenfelt, Thorsten, 53 *Parliament Street, London, S.W.* |
| 1869 | *Norris, W. G., *Coalbrookdale, Salop.* |
| 1880 | Nursey, Perry F., 161 *Fleet Street, London, E.C.* |
| | |
| 1889 | Oakes, Gerard R. *Riddings, Alfreton.* |
| 1869 | *Oakes, Thomas H., *Alfreton Works, Alfreton, Derbyshire.* |
| 1880 | Ogden, Samuel, *Werneth House, Oldham.* |
| 1883 | Ogilvie, A. G., 4 *Great George Street, London, S.W.* |
| 1883 | Ogle, Percy Jno., 4 *Bishopsgate Street Within, London, E.C.* |
| 1875 | Ogle, Richard, 4 *St. Ann's Square, Manchester.* |
| 1884 | Oliver, D. B., 114 *First Avenue, Pittsburg, Pennsylvania, U.S.A.* |
| 1884 | Oliver, H. W., Jun., 114 *First Avenue, Pittsburg, Pennsylvania, U.S.A.* |
| 1881 | Onions, Edward, *Ardsley House, East Ardsley, near Wakefield.* |
| 1887 | Ordoñez, Escandon Salvador y, *c/o M. Cardeñosa,* 20 *Mark Lane, London.* |

Elected Member

1872 Ormiston, J. W.,
*Douglas Gardens, Uddingston, near Glasgow.*
1877 Osborn, Samuel,
*Clyde Steel and Iron Works, Sheffield.*
1889 Otis, Charles Augustus,
*Otis Iron and Steel Company, Cleveland, Ohio, U.S.A.*
1884 Otto, Dr. C.,
*Dahlhausen, Ruhr, Germany.*
1879 Outine, Nicolas,
20 *Rue Froissart, Brussels.*
1889 Owen, David,
*Morriston, R.S.O., Glamorganshire.*
1888 Owen, Herbert James,
*The Mount, Ketley, Wellington, Salop.*

1881 Packer, Geo. S.,
*Hallside Steel Works, Glasgow.*
1878 Page, John,
*Penkridge, near Stafford.*
1869 *Page, Thomas,
*Roway Iron Works, West Bromwich.*
1877 Paget, Arthur,
*Loughborough.*
1875 Paget, Berkeley,
2 *Laurence Pountney Hill, London, E.C.*
1882 Palchondhuri, B.,
*Moheshgurig Factory, Krishnugsher, Bengal, India.*
1869 *Palmer, Sir Charles M., Bart., M.P.,
*Jarrow Iron Works, Newcastle-on-Tyne.*
1884 Panton, W. H.,
*Stockton Forge, Stockton-on-Tees.*
1873 Paris, William,
*Glasgow Iron Works, Glasgow.*
1874 Parke, G. H.,
*Barrow Rolling Stock Works, Barrow-in-Furness.*
1879 Parker, William,
2 *White Lion Court, Cornhill, London, E.C.*
1882 Parkes, Ebenezer,
*Atlas Iron Works, West Bromwich.*
1888 Parkes, Frank,
*Coldfield Works, Dartmouth Street, Birmingham.*
1882 Parkes, Henry P.,
*Tipton Chain, Cable, and Anchor Works, Tipton.*
1889 Parkes, John Israel,
*Eagle Works, Smethwick.*
1875 Parkyn, William J.,
*Engineering Works, Dukinfield, near Manchester.*

Elected Member

1881 Parratt, W.,
58 *Lyndhurst Road, Peckham, London, S.E.*

1869 *Parry, John,
*Ebbw Vale Iron Works, Newport, Monmouthshire.*

1874 Parsons, P. M.,
*Melbourne House, Blackheath, Kent.*

1888 Pasquier, Pierre,
*Directeur du Laminoir des Acieries, Dudelange, Grand duchi de Luxembourg.*

1879 Pastor, G.,
*Ruhrort, Germany.*

1878 Patchett, George,
*Manor Road, Halifax.*

1882 Patchett, James,
*Shropshire Iron Works, Hadley, Wellington, Salop.*

1887 Paterson, T S.
*Motherwell.*

1884 Paterson, John,
106 *Hawthorne Terrace, Workington.*

1886 Patterson, Anthony,
*Dowlais.*

1869 Pattinson, John,
75 *Side, Newcastle-on-Tyne.*

1874 Pattison, John,
*Naples, Italy.*

1887 Paton, John,
*Pontypool, Mon.*

1881 Paul, Fred. Wilson,
*Hallside Steel Works, Newton, Glasgow.*

1876 Peace, Maskell Wm.,
*Wigan.*

1878 Peake, John Nash,
*The Tileries, Tunstall, Staffordshire.*

1889 Pearce, Sir William George, Bart.,
*Cardell, Wemyss Bay, N.B.*

1885 Pearn, Frank,
*West Gorton, Manchester.*

1877 Pears, George,
*Witton House, Witton-le-Wear, Darlington.*

1883 Pearson, Jos. H.,
*Handsworth, near Birmingham.*

1875 Pearson Peter,
*Dunkirk Iron Works, West Bromwich.*

1873 Pearson, Thos. H.,
*Dallam Forge Company, Wigan.*

1883 Pearson, W. G.,
97 *Cannon Street, London, E.C.*

| Elected Member | |
|---|---|
| 1884 | Pease, Arthur,<br>*Darlington.* |
| 1888 | Pease, John Francis,<br>*Pierremont, Darlington.* |
| 1887 | Pease, Joseph Albert,<br>*Darlington.* |
| 1882 | Pease, Henry Fell, M.P.,<br>*Darlington.* |
| 1869 | *Pease, Sir Joseph W., Bart., M.P.,<br>*Hutton Hall, Guisbro', Yorks.* |
| 1875 | Pechin, E. C.,<br>303 *Prospect Street, Cleveland, Ohio, U.S.A.* |
| 1883 | Peech, W. H.,<br>*Phœnix Bessemer Steel Works, Ickles, near Sheffield.* |
| 1885 | Peile, Wm.,<br>*Cartgate, Hensingham, Whitehaven.* |
| 1880 | Pendred, V.,<br>163 *Strand, London, W.C.* |
| 1881 | Pepper, Joseph E.,<br>*Clarence Iron Works, Leeds.* |
| 1884 | Percy, Thomas McLeod,<br>*Wigan Coal and Iron Works, Wigan.* |
| 1884 | Perks, George Henry,<br>*Elter-Water Hall, Ambleside.* |
| 1879 | Pernot, Chas.,<br>*St. Chamond, Loire, France.* |
| 1889 | Peters, Theodor,<br>14 *Wichmannstrasse, Berlin.* |
| 1885 | Petherick, John,<br>*Consett Iron Works, Blackhill, Co. Durham.* |
| 1873 | Petin, Jean J. Hippolyte,<br>*Rue Mont Grand* 24, *Marseilles, France.* |
| 1874 | Peto, Samuel Arthur,<br>*Plumbago Crucible Works, Battersea, London, S.W.* |
| 1883 | Phipps, Hy., Jun.,<br>*Pittsburg, Pa., U.S.A.* |
| 1874 | Piedbœuf, Gustave,<br>*Aix-la-Chapelle.* |
| 1884 | Pierce, J. J.,<br>*Sharpsville, Pennsylvania, U.S.A.* |
| 1886 | Pilkington, Herbert,<br>*Barnfield House, Tipton.* |
| 1887 | Ping, Francis,<br>*The Avenue, Linthorpe, Middlesbrough.* |
| 1876 | Pink, Richard,<br>6 *Sedars Strasse, Hanover, Germany.* |
| 1882 | Pirie, Lewis J.,<br>*King William's* Town, Cape Colony, South Africa. |

| Elected Member | |
|---|---|
| 1883 | Platt, Jas. E.,<br>*Messrs. Platt Brothers, Oldham.* |
| 1882 | Platt, James,<br>*Atlas Iron Works, Gloucester.* |
| 1873 | Platt, Samuel R.,<br>*Werneth Park, Oldham.* |
| 1889 | Pochin, Henry D.,<br>*Bodnant Hall, Eghoysbach, R.S.O., Denbighshire.* |
| 1881 | Poensgen, Carl,<br>*Düsseldorf, Germany.* |
| 1881 | Poensgen, Rudolph,<br>*Düsseldorf, Germany.* |
| 1881 | Ponthière, Honoré,<br>*Louvain University, Belgium.* |
| 1886 | Polson, John,<br>*Castle Levan, Greenock, N.B.* |
| 1887 | Pope, Samuel,<br>*Tinsley House, Tinsley, Sheffield.* |
| 1885 | Potter, E. C.,<br>*South Chicago Works, Chicago, U.S.A.* |
| 1872 | Potts, John Thorpe,<br>1001 *Chestnut Street, Philadelphia, U.S.A.* |
| 1879 | Pourcel, Alexandre,<br>*Saltburn-by-the-Sea.* |
| 1883 | Powell, W. H.,<br>*Ebbw Vale, Monmouthshire.* |
| 1889 | Preston, Fredk. Walter,<br>*Kettering Iron and Coal Company, Kettering.* |
| 1878 | Price, John,<br>6 *Osborne Villas, Jesmond, Newcastle-on-Tyne.* |
| 1874 | Price, Joseph, Jun.,<br>*Brunswick Foundry, Liverpool.* |
| 1883 | Prochaska, J.,<br>*Graz Steel Works, Graz, Austria.* |
| 1869 | *Putnam, William,<br>*Darlington Forge, Darlington.* |
| 1884 | Putnam, Thomas,<br>*Darlington Forge, Darlington.* |
| 1881 | Pye-Smith, Arnold,<br>32 *Queen Victoria Street, E.C.* |
| 1885 | Radcliffe, Francis,<br>233 *Burridge Road, Plumstead, London, S.E.* |
| 1879 | Radford, R. H.,<br>15 *St. James's Row, Sheffield.* |

| Elected Member | |
|---|---|
| 1874 | Ramage, John, *Beckenham, Kent.* |
| 1869 | *Ramsbottom, John, *Fernhill, Alderly Edge, Cheshire.* |
| 1869 | *Ramsden, Sir James, *Barrow-in-Furness.* |
| 1869 | *Ramsden, W. G., 13 *Tower Chambers, Liverpool.* |
| 1879 | Ransome, Allen, *Stanley Works, King's Road, Chelsea, S.W.* |
| 1887 | Ransome, Frederick, *Rushmere Lodge, Norwood Road, London, S.E.* |
| 1889 | Ransome, Robert James, *Water-side Works, Ipswich.* |
| 1874 | Rapier, Richard C., 5 *Westminster Chambers, London, S.W.* |
| 1888 | Rapley, Frederick Harvey, *Dashwood House, London, E.C.* |
| 1869 | *Ratliffe, George, 81 *Cannon Street Buildings, Cannon Street, E.C.* |
| 1874 | Ray, Edmund, *Lindal Moor Mines, Ulverston.* |
| 1871 | Reay, Thomas M., *Spennymoor, County Durham.* |
| 1882 | Reay, Thomas P., *Airedale Foundry, Leeds.* |
| 1870 | Reed, Sir E. J., M.P., *Broadway Chambers, Westminster, S.W.* |
| 1880 | Reichwald, A., *Newcastle-on-Tyne.* |
| 1889 | Reimers, E., 19 *Schonsbeckerstrasse, Magdeburg, Buckau, Germany.* |
| 1880 | Remaury, M., 56 *bis, rue de Chateaundun, Paris.* |
| 1883 | Rendel, W. Stuart, 8 *Great George Street, Westminster.* |
| 1878 | Renton, Benjamin Mann, *Savile Street, Sheffield.* |
| 1886 | Resimont, Armand, *Valenciennes, Nord, France.* |
| 1885 | Reynolds, George B., 23 *Longridge Road, Earl's Court, S.W.* |
| 1881 | Reynolds, Thos., 99 *Cromwell Road, South Kensington, S.W.* |
| 1887 | Rhodes, George W., *The Cottage, Victoria Park, Manchester.* |
| 1889 | Richards, David, *Hillside, Ammanford, Carmarthenshire.* |

Elected Member

1869 *Richards, Edwin,
*Pyle and Blaina Works, Blaina, R.S.O., Monmouthshire.*

1869 *Richards, E. Windsor,
*Lowmoor House, Lowmoor.*

1869 *Richards, J. J.,
*Atlas Steel Works, Sheffield.*

1869 Richards, Job,
*Havelock House, Shirley Road, Acock's Green, Birmingham.*

1869 *Richards, L.,
13 *Charlotte Street, Dowlais.*

1882 Richardson, George,
98 *Westbourne Terrace, London, W.*

1869 *Richardson, Joseph,
*Stockton-on-Tees.*

1869 *Richardson, Thomas, M.P.,
*West Hartlepool.*

1872 Richardson, T. G.,
*Killamarsh Forge, Chesterfield.*

1869 *Richardson, W.
*Platt Brothers' Works, Oldham.*

1881 Richter, Carl,
*Französische Strasse,* 60, *Berlin, Germany.*

1875 Ridehalgh, G. J. M.,
*Fell Foot, Newby Bridge, Ulverston.*

1889 Ridgely, William Barrett,
*Springfield Iron Company, Springfield, Illinois, U.S.A.*

1869 *Ridley, J. C.,
3 *Summerhill Grove, Newcastle-on-Tyne.*

1877 Ridley, T. D.,
*Coatham, Redcar.*

1883 Ridsdale, C. H.,
*Hutton Grange, Guisbrough, Yorkshire.*

1873 Riley, Edward,
2 *City Road, Finsbury Square, London, E.C.*

1874 Riley, James,
23 *Royal Exchange Square, Glasgow.*

1873 Ripley, Hugh,
*Bowling Dye Works, Bradford.*

1882 Ritson, John H. R.,
*Aberdulais, near Neath, S. Wales.*

1881 Rixon, A. W.,
10 *Austin Friars, London, E.C.*

1881 Roberts-Austen, W. Chandler, F.R.S.,
*Royal Mint, London, E.*

1888 Roberts, James,
*Swan Foundry, West Bromwich.*

1885 Robertson, Daniel A. W.,
*South Russell Street, Grahamston, Falkirk.*

| Elected Member | |
|---|---|
| 1885 | Robertson, Henry B.,<br>*Palé Corwen, South Wales.* |
| 1869 | *Robinson, John,<br>*Westwood Hall, Leek, Staffordshire.* |
| 1888 | Robinson, John Fred.,<br>*Atlas Works, Sheffield.* |
| 1881 | Robinson, R.,<br>*Howlish Hall, Bishop Auckland.* |
| 1881 | Robinson, Sydney J.,<br>*Brightside Steel Works, Sheffield.* |
| 1879 | Robinson, T. N.,<br>*Railways Works, Rochdale.* |
| 1870 | Robson, Edward,<br>*Leatham House, Redcar.* |
| 1884 | Robson, Niel,<br>5 *Dixon Street, Glasgow.* |
| 1880 | Rocour, G.,<br>18 *Avenue Rogier, Liége, Belgium.* |
| 1889 | Roe, Pearce,<br>10 *Foulser Road, Upper Tooting, S.W.* |
| 1883 | Roepper, C. W.,<br>*Solid Steel Company, Alliance, Ohio, U.S.A.* |
| 1873 | Rogé, Xavier,<br>*Pont-à-Mousson, Meurthe, France.* |
| 1878 | Rogers, John Henry,<br>*South Wales Iron Works, Llanelly.* |
| 1870 | Rogerson, John,<br>*Croxdale Hall, Durham.* |
| 1889 | Rognetta, F. B., Colonel,<br>181 *Via Nazionale, Rome, Italy.* |
| 1885 | Rollason, James,<br>*Bromford Wire Mills, Erdington, Birmingham.* |
| 1874 | Ronna, A.,<br>*I. Schellinggasse* 5, *Wien, Austria.* |
| 1882 | Roscoe, Sir Henry, M.P., F.R.S.,<br>10 *Bramham Gardens, London, S.W.* |
| 1875 | Roseby, W. J.,<br>*Lindum Iron Ore Company, Lincoln.* |
| 1875 | Ross, Edward,<br>*M. S. and L. Railway, Marple, Cheshire.* |
| 1869 | *Round, B.,<br>*Hange Furnaces, Tividale, Tipton.* |
| 1875 | Rummens, Chas.,<br>8 *Oldfield Terrace, Acton Vale, W.* |
| 1870 | Rummens, Francis,<br>54 *Warrington Crescent, Maida Vale, London, W* |
| 1889 | Rummens, Francis William,<br>*Shirley, near Southampton.* |

Elected Member

1888 Ruscoe, John,
*Hyde, near Manchester.*

1877 Russell, Emil,
*Die Direction der Disconts Gesellschaft, Berlin.*

1882 Russell, John,
8 *Victoria Chambers, Westminster.*

1883 Russell, W.,
*Pather Iron Works, Wishaw, N.B.*

1885 Russell, Robert,
*Coltness Iron Works, Newmains, N.B.*

1886 Russell, George,
*Summerlee Iron Works, Coatbridge, N.B.*

1882 Sach, Augustus T.,
*Beech House, Bowdon, near Altringham.*

1877 Sacré, Alfred Louis,
60 *Queen Victoria Street, London, E.C.*

1887 St. Oswald, Lord,
*Nostell Priory, Wakefield.*

1880 Salmon, F. B.,
*Birkenhead Forge, Birkenhead.*

1880 Salter, M.,
*Workington.*

1889 Sampson, Richard H.,
*Pontardulais, South Wales.*

1886 Samuel, James,
*Glengarnock, N.B.*

1869 *Samuelson, Sir B., Bart., M.P.,
56 *Prince's Gate, South Kensington, S.W.*

1885 Samuelson, Francis A. E.,
*Sockburn Hall, Darlington.*

1887 Sandahl, Carl J.,
*Trimsaran, S. Wales.*

1877 Sartoris, Herbert,
*Kettering Furnaces, Kettering.*

1887 Saunders, James,
86 *Darlington Street, Wolverhampton.*

1889 Sauvée, Albert,
22 *Parliament Street, London, S.W.*

1875 Sawrey, John S.,
*Fell Side, Pennington, near Ulverston.*

1872 Scattergood, J.,
*Stour Valley Works, Spon Lane, Birmingham.*

1883 Schlegtendal, F.,
*Duisburg, Germany.*

| Elected Member | |
|---|---|
| 1882 | Schlink, Joseph, *Friedrich-Wilhelmshütte, Mulheim-on-the-Ruhr, Germany.* |
| 1876 | Schneider, Henry, *Creusôt, France.* |
| 1875 | Schofield, C. J., *Clayton, near Manchester.* |
| 1881 | Schott, Robert, *Dannemora Steel Works, Sheffield.* |
| 1888 | Schrodter, E., *Secretary, German Ironmasters' Association, Dusseldorf, Germany.* |
| 1884 | Schroller, Wm. C. P. H., 20 *Mount Street, Manchester.* |
| 1885 | Schultz, George, *Botolph House, Eastcheap, E.C.* |
| 1884 | Schulz, G., 8 *Friedrichstrasse, Bochum, Westphalia.* |
| 1881 | Scott, Ernest, *Close Works, Newcastle-on-Tyne.* |
| 1878 | Scott, Fife J., *Newcastle-on-Tyne.* |
| 1882 | Scott, Ralph G., *Monkbridge Iron Works, Leeds.* |
| 1878 | Scott, William Henry, *Newcastle-on-Tyne.* |
| 1888 | Scoular, George, *Hensingham, Whitehaven.* |
| 1882 | Seaman, Fred., *Oak Mount, Adelaide Road, Brincliffe, Sheffield.* |
| 1880 | Seddon, R. B., *Wigan.* |
| 1883 | Seebeck, Leopold, *Crosby Buildings, Crosby Square, E.C.* |
| 1877 | Seebohm, Henry, 22 *Courtfield Gardens, South Kensington.* |
| 1889 | Seehoff, Robert, *Witten, Westphalia, Germany.* |
| 1874 | Sellers, William, 1600 *Hamilton Street, Philadelphia, U.S.A.* |
| 1881 | Senior, George, *Pond's Forge, Sheffield.* |
| 1888 | Sennett, Richard, *Messrs. Maudslay, Sons, & Field, Ld., Engineers, Lambeth.* |
| 1879 | Sepulchre, A., *Aulnoye-lez-Berlaiemont, France.* |
| 1878 | Sepulchre, François, *Vezin, Belgium.* |

| Elected Member | |
|---|---|
| 1880 | Shakell, W. H., *Weardale Iron and Coal Co., Limited, George Yard, Upper Thames Street, London, E.C.* |
| 1886 | Share, Geo. W., 72 *King William Street, London, E.C.* |
| 1869 | *Sharp, Henry, *Bolton Iron and Steel Works, Bolton.* |
| 1883 | Sharp, J., 5 *St. Bernard's Crescent, Edinburgh.* |
| 1872 | Shaw, William, Sen., *The Cast Steel Foundry, Middlesbrough.* |
| 1888 | Sheldon, John George, *Seaton Carew.* |
| 1869 | *Shield, Clifton, *Reform Club, Pall Mall, London.* |
| 1878 | Shinn, William P., *New England Railway Co.*, 36 *Wall Street, New York, U.S.A.* |
| 1883 | Shipman, John W., *Attercliffe Steel Wire Mills, Sheffield.* |
| 1889 | Siddell, George, *Roewood, Crabtree, Pitsmoor, Sheffield.* |
| 1878 | Siemens, Alexander, 12 *Queen Anne's Gate, Westminster, London, S.W.* |
| 1884 | Siemens, Frederick, 12 *Queen Anne's Gate, Westminster, London, S.W.* |
| 1876 | Siltzer, John, 4 *Cromwell Houses, South Kensington, London, S.W.* |
| 1883 | Simmons, Charles, *Darlington Steel Works, Darlington.* |
| 1874 | Simon, Henry, 20 *Mount Street, Manchester.* |
| 1883 | Simons, D., *Moss Bay Steel Works, Workington.* |
| 1880 | Simpson, F. F., *Park Lane Iron Works, Oldbury.* |
| 1877 | Simpson, J. B., *Hedgefield House, Blaydon-on-Tyne.* |
| 1888 | Simpson, Joseph, *Moss Close, Walsall.* |
| 1874 | Simpson, J. S., *Harrington Iron Works, Harrington, Cumberland.* |
| 1876 | Simpson, William W., *Oswaldtwistle Collieries, near Accrington.* |
| 1884 | Simpson, Henry Charles, *Horsehay, near Wellington, Shropshire.* |
| 1885 | Simpson, Matthew H., *Queen Street, Lancaster.* |

| Elected Member | |
|---|---|
| 1886 | Simpson, Robert, *Harrington, Cumberland.* |
| 1889 | Slater, James, *Bescot Hill, Walsall.* |
| 1874 | Smith, Charles, *Steel Works, Barrow-in-Furness.* |
| 1881 | Smith, C. Weston, *Langland Hall, Mumbles, South Wales.* |
| 1869 | *Smith, E. Fisher, 34 *Avenue Road, Regent's Park, London, N.W.* |
| 1882 | Smith, Fred., *Caledonia Works, Halifax, Yorkshire.* |
| 1882 | Smith, G. Jackson, *Clyde Street Works, Sheffield.* |
| 1889 | Smith, Henry John, *Newmains, N.B.* |
| 1880 | Smith, Jno. Jos., *Southwood House, Eltham, Kent.* |
| 1869 | *Smith, John Stores, *Sheepbridge Iron Works, Chesterfield.* |
| 1882 | Smith, Joseph H., *Summerhill, Kingswinford, near Dudley.* |
| 1869 | *Smith, Josiah T., *Rhine Hill, Stratford-on-Avon.* |
| 1887 | Smith, Richard, *Royal School of Mines, S. Kensington, London.* |
| 1874 | Smith, Robert, *Castle Hill, Sheffield.* |
| 1889 | Smith, Samuel, *Monway Steel Works, Wednesbury.* |
| 1876 | Smith, Thomas Taylor, *Greencroft Park, Durham.* |
| 1885 | Smith, Watson, *University College, Gower Street, W.* |
| 1884 | Smith, W. A., *Heyford Iron Works, near Weedon, Northampton.* |
| 1877 | Smith, W. Ford, *Gresley Iron Works, Manchester.* |
| 1876 | Smyth, Samuel Richard, 2 *Ducie Street, Clapham, S.W.* |
| 1869 | *Snelus, G. J., F.R.S., *West Cumberland Iron and Steel Works, Workington.* |
| 1884 | Soldenhoff, Richard de, 71 *St. Mary's Street, Cardiff.* |
| 1884 | Somers, Walter, *Hayword Forge, Birmingham.* |
| 1884 | Sorby, T. W., *Storthfield, Sheffield.* |

Elected Member

1886 Sorby, Henry C., F.R.S.,
*Broomfield, Sheffield.*

1885 Sotomayor, Major F. Alvarez,
*Ordnance Works, Trubia, Spain.*

1872 Sparrow, Arthur,
*Preese Manor, Shrewsbury.*

1889 Sparrow, Henry,
*Himley, Dudley.*

1873 Sparrow, J. W.,
*Beckminster, Wolverhampton.*

1889 Spencer, Charles,
*West Stockton-on-Tees Iron Works, Stockton.*

1869 Spencer, John,
*Phœnix Works, Coatbridge, N.B.*

1888 Spencer, John,
*Globe Tube Works, Wednesbury.*

1884 Spencer, J. Cuthbert,
*Walbottle Hall, Newcastle-on-Tyne.*

1879 Spencer, J. W.,
*Newburn Steel Works, Newcastle-on-Tyne.*

1869 *Spencer, Thomas,
*The Grove, Ryton, Blaydon-on-Tyne.*

1880 Squire, Edw. L.,
*Coalbrookdale Iron Works, Shropshire.*

1888 Squire, Lionel R. Littler,
30 *St. John's Wood Park, London, N.W.*

1878 Stanger, William Harry,
*Chemical Laboratory and Testing Works, Broadway, Westminster, S.W.*

1881 Stanley, John W.,
*The Laboratory, Tondu, Bridgend, Glamorganshire.*

1873 Stead, J. E.,
5 *Zetland Road, Middlesbrough.*

1886 Steel, Henry, Jun.,
*Phœnix Steel Works, Ickles, Sheffield.*

1886 Steel, Wm.,
*Phœnix Steel Works, Ickles, Sheffield.*

1873 Steer, Edward,
*Castle Works, Tydu, near Newport, Monmouthshire.*

1885 Stephenson, Robert,
*Stockton Malleable Iron Company, Stockton-on-Tees.*

1877 Sterne, Louis,
2 *Victoria Mansions, Westminster, S.W.*

1880 Steven, Thos.,
*Milton Iron Works, Glasgow.*

1875 Stevens, Warwick Allan,
*Darlington Works, Southwark Bridge Road, London.*

| Elected Member | |
|---|---|
| 1869 | *Stevenson, John, *Acklam Iron Works, Middlesbrough.* |
| 1873 | Stewart, Andrew, 41 *Oswald Street, Glasgow.* |
| 1873 | Stewart, James, 41 *Oswald Street, Glasgow.* |
| 1883 | Stewart, Peter, *Tharsis Sulphur and Copper Co., Glasgow.* |
| 1874 | Stileman, F. C., 23 *Great George Street, Westminster, S.W.* |
| 1876 | Stoddart, Charles John, *Parkgate Iron Works, Rotherham.* |
| 1872 | Stoker, F. W., *Easton & Anderson Co. (Ld.), Erith Iron Works, Erith, K* |
| 1880 | Storey, Sir Thomas, *Lancaster.* |
| 1884 | Storey, E., 1 *Rumford Place, Liverpool.* |
| 1888 | Storey, Thomas E., *Kidsgrove, Staffordshire.* |
| 1887 | Storey, Wm. John Patrickson, *Douglas House, Rhyl, N. Wales.* |
| 1888 | Storr, Frederick, 21 *The Groves, Chester.* |
| 1886 | Storr, Walter W., 11 *Temple Street, Swansea, Glamorganshire, South Wal* |
| 1885 | Straker, Herbert, *Thornaby Iron Works, Stockton-on-Tees.* |
| 1879 | Strang, J. H., *Lochburn Iron Works, Glasgow.* |
| 1883 | Strange, A. J., *West Cumberland Iron and Steel Works, Workington.* |
| 1876 | Strick, George Henry, *Amman Iron Works, Swansea.* |
| 1880 | Strick, Jno., *Bar Hill, Madeley, Staffordshire.* |
| 1889 | Stroudley, W., *Locomotive Engineer, Brighton.* |
| 1883 | Stuart, Professor J., M.P., *University, Cambridge.* |
| 1881 | Stubbs, Frederick, *Broomfield, Newbould Lane, Sheffield.* |
| 1885 | Sturrock, David, *Carntyne Iron Co., Glasgow.* |
| 1872 | Summers, James W., *Globe Iron Works, Staleybridge.* |
| 1872 | Sumner, William, *Brazenose Street, Manchester.* |

| Elected Member | |
|---|---|
| 1876 | Sutcliffe, F. John Ramsbottom, *Low Moor Iron Works, Bradford, Yorks.* |
| 1872 | Sutherland, The Duke of, K.G., *Stafford House, St. James's, London.* |
| 1883 | Sutherland, Wm., *Poplar Avenue, Sandon Road, Birmingham.* |
| 1873 | Swan, Edward W., *Middlesbrough.* |
| 1873 | Swan, Herbert A., *Middlesbrough.* |
| 1874 | Swan, Henry F., *North Jesmond, Newcastle-on-Tyne.* |
| 1869 | *Swan, John G., *Cargo Fleet Iron Works, Middlesbrough.* |
| 1869 | *Swindell, J. E., *Cradley Iron Works, Stourbridge.* |
| 1881 | Sykes, Robert, *Acres House, Stalybridge.* |
| | |
| 1879 | Tait, James, *Raisby Hill Lime Works, Coxhoe, County Durham.* |
| 1869 | Tate, John, *Workington Hematite Iron and Steel Co. (Ld.), Workington.* |
| 1875 | Tatham, Thomas, 102 *Corporation Street, Manchester.* |
| 1880 | Taylor, James, *Shirecliffe Cottage, Shirecliffe Lane, Sheffield.* |
| 1888 | Taylor, Joseph Samuel, *Derwent Foundry, Birmingham.* |
| 1876 | Taylor, T. A. O., *Clarence Iron Works, Leeds.* |
| 1887 | Taylor, James, *Park House, Queen's Road, Oldham.* |
| 1887 | Tench, Wm. R., *Hamilton Iron Works, Garston, near Liverpool.* |
| 1879 | Tennant, Sir Charles, Bart., *St. Vincent Street, Glasgow.* |
| 1885 | Thackray, Wm., Jun., 7 *The Avenue, Sunderland.* |
| 1875 | Thielen, Alex., *Phœnix Iron Works, Ruhrort, Rhenish Prussia.* |
| 1888 | Thomas, James Lewis, *Bryn Awel, Aberdare.* |
| 1889 | Thomas, John Glyn, *Llangennech, South Wales.* |

| Elected Member | |
|---|---|
| 1888 | Thomas, Richard, *Birchill's Iron Works, near Walsall.* |
| 1881 | Thomas, R. B., *Lydbrook, Gloucestershire.* |
| 1878 | Thomas, William, *Bryn Awel, Aberdare.* |
| 1888 | Thomas, William, *Portway Works, Wednesbury.* |
| 1878 | Thomas, William Henry, 15 *Parliament Street, S.W.* |
| 1882 | Thomlinson, Wm., *Seaton Carew, near West Hartlepool.* |
| 1882 | Thompson, Sir Henry M. Meysey, Bart., *Kirby Hall, York.* |
| 1882 | Thompson, James, *Singleton Park, Kendal.* |
| 1889 | Thompson, Philip, *Clarence Iron Works, Middlesbrough.* |
| 1883 | Thompson, S. Jno., *Muchall Grove, Wolverhampton.* |
| 1886 | Thompson, Robert, *Fulwell West House, Sunderland.* |
| 1879 | Thomson, Charles, *Calder Iron Works, Coatbridge, N.B.* |
| 1873 | Thomson, Graham H., 129 *Trongate, Glasgow.* |
| 1882 | Thomson, James R., *Clyde Bank, Dumbartonshire.* |
| 1869 | *Thomson, J. M., *Calder Iron Works, Glasgow.* |
| 1878 | Thomson, John, *Eston Mines, near Middlesbro'-on-Tees.* |
| 1881 | Thwaites, Edward H., *Vulcan Iron Works, Bradford, Yorks.* |
| 1871 | Tinn, Joseph, *Bristol Bank Buildings, Bristol.* |
| 1874 | Todd, Hadden W., *St. Helens, Lancashire.* |
| 1884 | Tolmie, A. D., 166 *Buchanan Street, Glasgow.* |
| 1882 | Tomkys, Joseph, *Carr House Iron Works, West Hartlepool.* |
| 1889 | Tompkin, John Benjamin, *Newhall Steel Works, Sheffield.* |
| 1885 | Tonks, Edwin, *Holly Cottage, West Smethwick.* |
| 1870 | Tosh, E. G., *North* Lonsdale Iron and Steel Company, Ulverston. |

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| Elected Member | |
|---|---|
| 1870 | Tosh, George, *North Lincolnshire Iron Works, Scunthorpe, Doncaster.* |
| 1881 | Tosh, R. George, *North Lincolnshire Iron Works, Scunthorpe, Doncaster.* |
| 1883 | Tozer, Wm., *Phœnix Bessemer Steel Works, Ickles, near Sheffield.* |
| 1883 | Trasenster, Paul, *Boulevard Frère-Orban, 4, Liége, Belgium.* |
| 1889 | Triponé, Emile, 35 *Rue de Rome, Paris.* |
| 1881 | Trubshaw, Ernest, *Western Tin Plate Works, Llanelly, South Wales.* |
| 1880 | Tucker, A. E., *Holly Street, Smethwick.* |
| 1886 | Turner, Thomas, *Corngreaves Iron Works, near Birmingham.* |
| 1887 | Turner, Thomas, *Mason Science College, Birmingham.* |
| 1884 | Turton, Geo., *Patent Buffer Steel and File Works, Sheffield.* |
| 1884 | Turton, John, *Vulcan Forge and Rolling Mills, Sheffield.* |
| 1885 | Tweedie, Jas. A., 12 *St. Andrew Square, Edinburgh.* |
| 1889 | Twynam, Thomas, 7 *Marlborough Terrace, Bedford Park, London, W.* |
| 1889 | Tylden-Wright, Charles, *The Priory, Dudley.* |
| 1887 | Tyzack, Wm. A., *Stella Works, Hereford Street, Sheffield.* |
| | |
| 1879 | Upton, Douglas, *Codnor Park, Alfreton.* |
| | |
| 1874 | Valentine, Charles J., *Marshside, Workington.* |
| 1875 | Valton, Ferdinand, 166 *Fauborg St. Honoré, Paris.* |
| 1886 | Varley, John, *Leeds Forge Co., Leeds.* |
| 1883 | Vapart, M., *Angleur, near Liége, Belgium.* |
| 1873 | Vaughan, Cedric, *Hodbarrow Mines, Millom, Cumberland.* |
| 1885 | Verdié, E., 75 *Rue de la Victories, Paris.* |

| Elected Member | |
|---|---|
| 1869 | *Vickers, T. E.,<br>*River Don Works, Sheffield.* |
| 1881 | Vitoria, José Felix,<br>*Bilbao, Spain.* |
| 1883 | Vivian, John,<br>*Whitehaven.* |
| 1869 | *Waddington, Joseph,<br>*Iron Foundry, Barrow-in-Furness.* |
| 1870 | Wadham, Edward,<br>*Milwood, Dalton-in-Furness.* |
| 1883 | Wailes, J. W.,<br>*Patent Shaft and Axletree Company, Wednesbury.* |
| 1885 | Wake, Henry H.,<br>*River Wear Commission, Sunderland.* |
| 1886 | Walker, C. C.,<br>*Lilleshall, Old Hall, near Newport, Shropshire.* |
| 1869 | *Walker, B.,<br>*Goodman Street Works, Leeds.* |
| 1875 | Walker, John Scarisbrick,<br>*Pagefield Iron Works, Wigan.* |
| 1874 | Walker, William,<br>*Saltburn-by-the-Sea, Yorkshire.* |
| 1888 | Walker, William Edward,<br>*Whitehaven.* |
| 1888 | Walker, William Huginn, Jun.,<br>*Wicker Iron Works, Sheffield.* |
| 1889 | Walker, William Rose,<br>*Union Steel Company, Chicago, U.S.A.* |
| 1887 | Wallis, James J.,<br>10 *St. Swithin's Lane, London, E.C.* |
| 1869 | *Walmsley Thomas,<br>70 *Crook Street, Bolton.* |
| 1875 | Walton, John P.,<br>*Acomb, Hexham.* |
| 1878 | Walton, Joseph,<br>*Zetland Buildings, Middlesbrough.* |
| 1889 | Walton, Joseph Pearson,<br>*Campbell Street, Wishaw, N.B.* |
| 1869 | Ward, George,<br>*Bearnett House, Wolverhampton.* |
| 1869 | *Ward, Henry<br>*Priestfield Works, Wolverhampton.* |
| 1878 | Ware, Charles William,<br>37 *Grosvenor Place, Newcastle-on-Tyne.* |
| | Warren, Edwin Caleb,<br>120 *Queen Victoria Street, E.C.* |

| Elected Member | |
|---|---|
| 1888 | Warrington, Henry James, *Berry Hill Farm, Stoke-on-Trent.* |
| 1889 | Watt, John Landale Wilson, 3 *Alexandra Place, Dennistown, Glasgow.* |
| 1876 | Webb, F. W., *Chester Place, Crewe.* |
| 1873 | Webb, Henry, *Irwell Forge, Bury.* |
| 1872 | Webb, Henry A., *Church Street Chambers, Stourbridge.* |
| 1873 | Wedekind, Hermann, 158 *Fenchurch Street, London, E.C.* |
| 1878 | Weeks, Joseph D., *Pittsburg, Pa., U.S.A.* |
| 1872 | Weir, William, *Gartsherrie Iron Works, Coatbridge, N.B.* |
| 1878 | Wellman, Samuel J., 1080 *Willson Avenue, Cleveland, Ohio, U.S.A.* |
| 1882 | Wells, Charles, *Moxley Steel and Iron Works, near Wednesbury.* |
| 1872 | Wendel, Henri de, *Hayange, Lorraine, Germany.* |
| 1872 | Wendel, Robert de, *Hayange, Lorraine, Germany.* |
| 1889 | Western, Chas. Robert, *Broadway Chambers, London, S.W.* |
| 1878 | Westmacott, Percy, *Benwell Hill, Newcastle-on-Tyne.* |
| 1871 | Wheelock, Jerome, *Worcester, Mass., U.S.A.* |
| 1879 | While, Adolph S., 32 *Regent Street, New Swindon.* |
| 1883 | While, Charles, *Curwen Street, Workington.* |
| 1879 | While, J. M., *Darlington Steel Works, Darlington.* |
| 1883 | Whipham, A. H., *Queen's Square, Middlesbrough.* |
| 1883 | White, Hy., *Derwent House, Gold Tops, Newport, Mon.* |
| 1887 | White, Henry, *Bridge Street, Worksop.* |
| 1885 | White, John Henry, *Derwent Works, Workington.* |
| 1889 | White, Maunsel, *Bethlehem Iron Company, Bethlehem, Pa., U.S.A.* |
| 1873 | Whitehead, John, *Penwortham Priory, Preston, Lancashire.* |

| Elected Member | |
|---|---|
| 1886 | Whitelaw, Thomas,<br>*Wellington Street, Glasgow.* |
| 1885 | Whiteley, Henry J.,<br>*Lane House, Ulverston.* |
| 1881 | Whitehouse, D.,<br>*Abercarn, Newport, Mon.* |
| 1870 | Whitham, J.,<br>*Perseverance Iron Works, Leeds.* |
| 1873 | Whitley, Joseph,<br>*Railway Works, Leeds.* |
| 1888 | Whittle, John,<br>*Yarra House, Chorley, Lancashire.* |
| 1869 | *Whitwell, William,<br>*Thornaby Iron Works, Stockton-on-Tees.* |
| 1876 | Wickstead, Jos. Hartley *care of* J. Buckton & Co.,<br>*Well House Foundry, Leeds.* |
| 1889 | Widdop, Isaac,<br>*Don Iron Works, Mexbrough, Yorks.* |
| 1881 | Wigzell, Eustace,<br>*Sowerby Bridge, Yorkshire.* |
| 1888 | Wilkinson, George W.,<br>*Risca, Newport, Monmouthshire.* |
| 1882 | Wilkinson, George,<br>*Tividale Sheet Mills, Tipton.* |
| 1885 | Wilkinson, George W.,<br>*Whitehaven.* |
| 1888 | Wilkinson Thomas,<br>99 *Burngreave Road, Sheffield.* |
| 1884 | Willans, B.,<br>*Barrow-in-Furness.* |
| 1878 | Willans, John William,<br>*Mawson Buildings,* 28 *Deansgate, Manchester.* |
| 1878 | Willett, B.,<br>56 *Rue de Provence, Paris.* |
| 1875 | Williams, David,<br>*Pontypool Iron and Tinplate Co., Pontypool, Monmouthshire.* |
| 1883 | Williams, E. L.,<br>*Ship Canal Office, Manchester.* |
| 1880 | Williams, Illtyd.,<br>*Linthorpe Works, Middlesbrough.* |
| 1880 | Williams, Israel,<br>*Pontymoile House, Pontypool, Monmouthshire.* |
| 1889 | Williams, James,<br>*The Fields, Newport, Monmouthshire.* |
| 1880 | Williams, John,<br>*Rogerston House, Tydu, Newport, Monmouthshire.* |
| 1872 | Williams, Nicholas,<br>*Hodbarrow Mines, Millom, Cumberland.* |

Elected Member

1888 Williams, Penry,
*Linthorpe Iron Works, Middlesbrough.*

1889 Williams, Peter,
*Brymbo Steel Works, Wrexham.*

1869 Williams, Richard,
*Brunswick Iron Works, Wednesbury.*

1872 Williams, R. Price,
38 *Parliament Street, London, S.W.*

1874 Williams, Robert,
*Excelsior Iron Works, Wishaw, N.B.*

1869 Williams, Walter,
*Wednesbury Oak Iron Works, Tipton.*

1877 Williams, Wilfred,
*Newhall Works, Birmingham.*

1882 Williams, William,
*Upper Forest Steel and Tinplate Works, Swansea.*

1880 Williamson, R. H.,
*Oakhurst, Cockermouth.*

1873 Williamson, J. D.,
*Cargo Fleet, Middlesbrough.*

1877 Williamson, Richard,
*Workington, Cumberland.*

1885 Williamson, Thos.,
*Bairdsike, Mossend, N.B.*

1870 Willman, Charles,
*Middlesbrough.*

1869 *Wilson, Alexander,
*Workington.*

1875 Wilson, Alfred,
*Gas Furnace Engineer, Stafford.*

1873 Wilson, George,
*Murrayfield House, Murrayfield, Edinburgh.*

1889 Wilson, G. H., Lieutenant-Colonel,
*Erigh Arran, Bala, North Wales.*

1869 *Wilson, Isaac, M.P.,
*Nunthorpe Hall, Middlesbrough.*

1869 *Wilson, John Frederick,
*Tees Iron Works, Middlesbrough.*

1886 Wilson, R. Theo,
*Tees Iron Works, Middlesbrough.*

1884 Wilson, A. E.,
85 *Chancery Lane, London, W.C.*

1879 Wise, W. Lloyd,
46 *Lincoln's Inn Fields, W.C.*

1884 Witherow J P.,
*Pittsburg, U.S.A.*

1873 Withy, Edward,
*Avon Villa, Parnell, Auckland, New Zealand.*

| Elected Member | |
|---|---|
| 1884 | Withy, Henry, *Middleton Shipyard, West Hartlepool.* |
| 1882 | Wittgenstein, Karl, *I. Krugerstrasse* 18, *Vienna.* |
| 1881 | Wolfenden, William, *Vulcan Steel Works, Barrow-in-Furness.* |
| 1883 | Wood, B. G., *Wardsend Steel Works, Sheffield.* |
| 1874 | Wood, Charles, *Tees Iron Works, Middlesbrough.* |
| 1889 | Wood, Edward, *Red Bank Works, Manchester.* |
| 1885 | Wood, Edward M., 2 *Westminster Chambers, London, S.W.* |
| 1873 | Wood, George R., *Fairfield, Bothwell, N.B.* |
| 1871 | Wood, John, *Troon, N.B.* |
| 1885 | Wood, Reginald N., *Bignall Hill Colliery, Stafford.* |
| 1889 | Wood, Stuart, 1620 *Locust Street, Philadelphia, U.S.A.* |
| 1882 | Woodall, John W., 4 *Victoria Road, Jesmond Road, Newcastle-on-Tyne.* |
| 1879 | Woodcock, H. B., *Low Moor Iron Works, near Bradford.* |
| 1888 | Woodcock, Joshua, *Laburnum Cottage, Low Moor.* |
| 1889 | Woodward, Wm. C., *Biddulph Valley Iron Works, Stoke-on-Trent.* |
| 1889 | Woolcock, Henry, *Whitehaven.* |
| 1885 | Worsdell, T. W., *Locomotive Works, Gateshead-on-Tyne.* |
| 1877 | Worton, John, *Blaenavon Iron Works, Monmouthshire.* |
| 1883 | Wotherspoon, Jno., *Gartsherrie Cottage, Coatbridge, N.B.* |
| 1876 | Wraith, George Henry, *Tudhoe Iron Works, Spennymoor.* |
| 1887 | Wright, Albert Leslie, 2 *Hawthorne Terrace, Newcastle-on-Tyne.* |
| 1873 | Wright, J. Roper, *Elba Steel Works, Gower Road, near Swansea.* |
| 1887 | Wrightson, Stephen, *Carnforth Iron Works, Carnforth.* |
| 1872 | Wrightson, Thomas, *Teesdale Iron Works, Stockton-on-Tees.* |

| Elected Member | |
|---|---|
| 1871 | Würzburger, Philip,<br>*Creuznach, Rhenish Prussia.* |
| 1878 | Wynne, Francis George,<br>5 *Westminster Chambers, London, S.W.* |
| 1883 | Ybarra, Don José A. de,<br>*Ronda de Recoletos*, 3, *Madrid, Spain.* |
| 1883 | Ybarra, Tomas de Z.,<br>*Bilbao, Spain.* |
| 1884 | Young, Edmund B.,<br>*Bolckow, Vaughan, & Co., Middlesbrough.* |
| 1880 | Young, James,<br>*Lowmoor Iron Works, near Bradford.* |
| 1886 | Young, Robert,<br>*Victoria Street, London, S.W.* |
| 1889 | Zabalburn, Ramon de Jaurequi y,<br>*Bilbao, Spain.* |
| 1882 | Zeitz, Th.,<br>*St. Peter's Close, Sheffield.* |
| 1881 | Ziane, Jules,<br>2 *Rue Hotel des Monnaies, St. Giles, Brussels.* |

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